

# RESEARCH REPORT



## Case Studies of On-Site Stormwater Management Alternatives



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**CASE STUDIES OF ON-SITE STORMWATER  
MANAGEMENT ALTERNATIVES**

**- *FINAL REPORT* -**

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## Executive Summary

This report provides practical information to developers, landscape architects, and municipalities to promote stormwater best management practices (BMPs) at the level of the individual lot or a cluster of buildings. It will examine the costs and benefits of practical solutions as well as any barriers to implementation through a series of case studies.

Specifically, the study:

- documents case studies of lot- and cluster- level stormwater BMPs, including documentation of their key economic, technical, and implementation issues; and
- lists the key economic, technical, and implementation issues of other potential BMPs where relevant case studies are unavailable in Canada.

Other topics covered within the report include:

- an overview of key stormwater management issues.
- traditional stormwater management financing options.
- alternative lot- and cluster- level stormwater best management practices.
- a high-level overview of BMP functions, and
- descriptions of the ten stormwater best management practices, as well as effectiveness and economic analyses, and a discussion of implementation issues.

The material presented herein is based largely on a published literature review. Information was primarily drawn from North American sources, but not always Canadian sources. As such, the descriptions of best management practices presented here are put forward as initial steps in moving towards the implementation of lot- and cluster- level BMPs. Each can come in different shapes and varieties. Developers, architects, builders, planners, and others should seek detailed information from qualified experts in deciding whether or not to move forward in implementing a stormwater BMP.

Furthermore, much of the costing information is based on U.S. experience and may not be perfectly transferable to Canada. At the same time, relatively little cost information is available. The initial and on-going costs of stormwater best management practices also tend to be very site specific, and considerable variability can exist among cost experiences. Developers, architects, builders, planners, and others should seek detailed information from qualified experts in determining BMP costs.

## Résumé

La présente recherche offre aux promoteurs, aux architectes paysagistes et aux municipalités des renseignements d'ordre pratique dans le but de leur permettre de favoriser l'emploi de pratiques exemplaires de gestion des eaux pluviales touchant les lots individuels ou les groupes de bâtiments. Elle porte sur le coût et les avantages des solutions pratiques ainsi que sur tout obstacle à leur mise en application, grâce à une série d'études de cas.

Tout particulièrement, l'étude :

- décrit les études de cas consacrés aux pratiques exemplaires de gestion des eaux pluviales de lots ou de groupes de bâtiments, en plus de décrire les enjeux clés sur le plan économique, technique ou celui de la mise en application;
- énumère les enjeux clés sur le plan économique, technique et celui de la mise en application d'autres pratiques exemplaires possibles, faute d'études de cas pertinentes au Canada.

Voici les autres sujets traités dans la recherche :

- aperçu des enjeux clés de la gestion des eaux pluviales;
- options classiques de financement de la gestion des eaux pluviales;
- solutions de rechange en matière de pratiques exemplaires de gestion des eaux pluviales de lots ou de groupes de bâtiments;
- aperçu général des pratiques exemplaires;
- descriptions de dix pratiques exemplaires en matière de gestion des eaux pluviales, analyses coût-efficacité, et discussion des enjeux de mise en application.

La matière présentée ici est largement fondée sur le dépouillement de la documentation parue. L'information est principalement extraite de documents produits en Amérique du Nord, mais pas toujours de provenance canadienne. À ce titre, les descriptions des pratiques exemplaires présentées ici sont mises de l'avant comme premières étapes de la mise en application des pratiques exemplaires de gestion des eaux pluviales de lots et de groupes de bâtiments. Chacune a une forme et une variété qui lui sont propres. Les promoteurs, les architectes, les constructeurs, les urbanistes et les autres intervenants doivent obtenir des renseignements détaillés auprès d'experts avant de décider d'aller de l'avant avec la mise en application de pratiques exemplaires de gestion des eaux pluviales.

En outre, la plupart des renseignements sur les coûts de revient sont fondés sur la situation aux États-Unis et pourraient ne pas se transposer parfaitement au Canada. Par la même occasion, on dispose d'assez peu d'information sur les coûts. Le coût initial et les frais permanents des pratiques exemplaires de gestion des eaux pluviales sont généralement liés à un emplacement particulier et la situation des coûts peut varier énormément. Les promoteurs, les architectes, les constructeurs, les urbanistes et les autres intervenants doivent obtenir des renseignements détaillés auprès d'experts avant de déterminer le coût des pratiques exemplaires en matière de gestion des eaux pluviales.



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# 1 INTRODUCTION

## 1.1 Context

The Canadian housing industry provides residential shelter for Canadians, as well as facilities for business and leisure activities. It is a major engine, in fact like no other, of the Canadian economy. The residential construction sector afforded nearly 140,000 new housing starts in 1998, with building permits valued at over \$33 billion. This sector employs over 72,000 people directly in construction and development related activities, and has a direct and immediate contribution to gross domestic product of over \$12 billion annually.

The non-residential building construction sector supported building permits valued at another \$15 billion in 1998 (including industrial, commercial, and institutional development). It employs over 33,000 workers directly in construction and development related activities, countless others in supporting roles, and makes a direct contribution to gross domestic product of over \$7 billion.

**Exhibits 1.1 and 1.2** describe historic new housing starts and the new housing price index for Canada. Since about 1987, there has been a trend of declining new housing starts. Furthermore, the price of a new house has risen considerably since 1985. Given the substantial economic and social benefits conveyed by this industry, it is imperative that strategies be advanced that help ensure housing is available and affordable for all Canadians.

One increasingly important issue facing the housing industry is that of stormwater management. Stormwater management is focused on preventing or managing the numerous adverse economic, social, and environmental impacts of stormwater runoff.

The costs of failing to properly address stormwater challenges are enormous. At the national level, for example, the costs of improving Canada's municipal sewer system, including mains, storage tanks, and treatment plants, is about \$4 billion per year over 15 years (or about \$130 per capita per year across Canada).<sup>1</sup> The share of stormwater costs in this total is unknown.

At the municipal level, the capital and operating costs of stormwater infrastructure management are highly visible. So too are the costs of incomplete stormwater management. Consider the examples described in **Box 1.1**, all gathered by the Canadian Water and Wastewater Association (CWWA) from newspaper clippings in the year 2000 and spanning across Canada. Themes include:

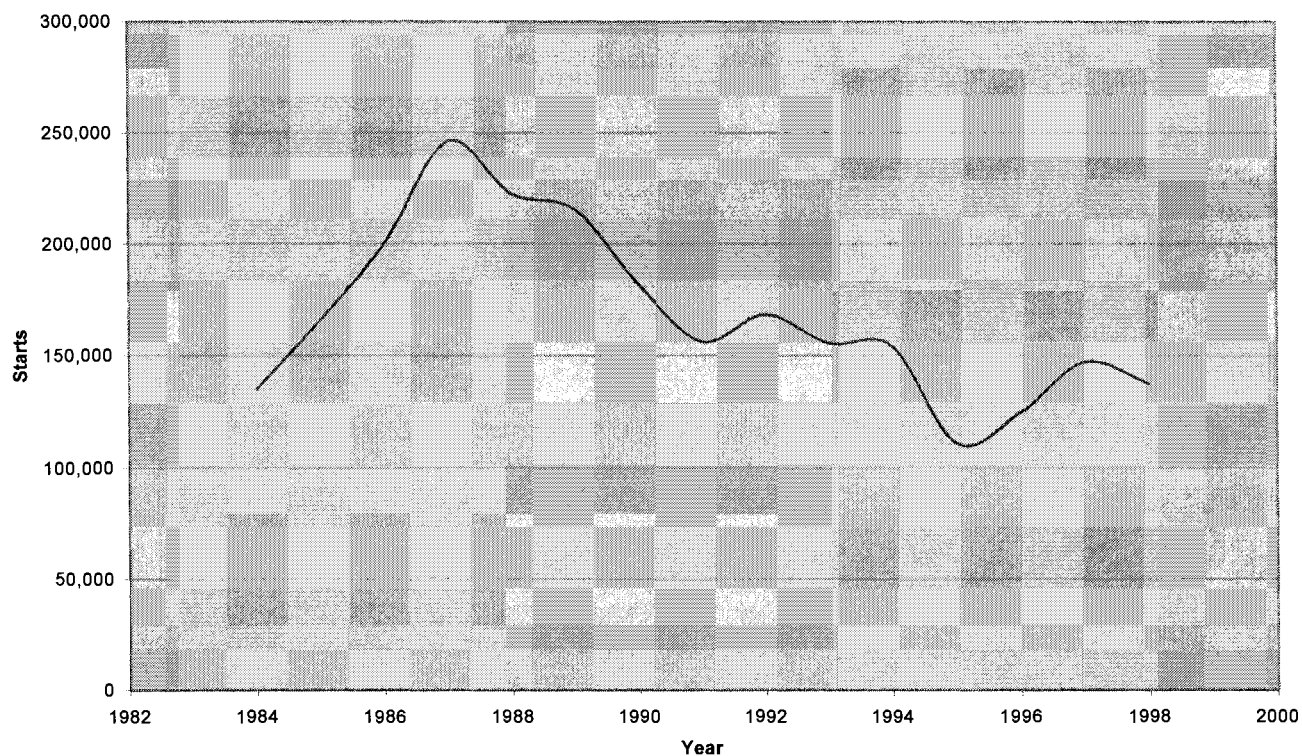
- underground infrastructure is aging and deteriorating;
- the costs of remediation are substantial, and of replacement are staggering;
- some municipalities are already development-constrained because of infrastructure; and
- innovative solutions are needed to overcome these challenges.

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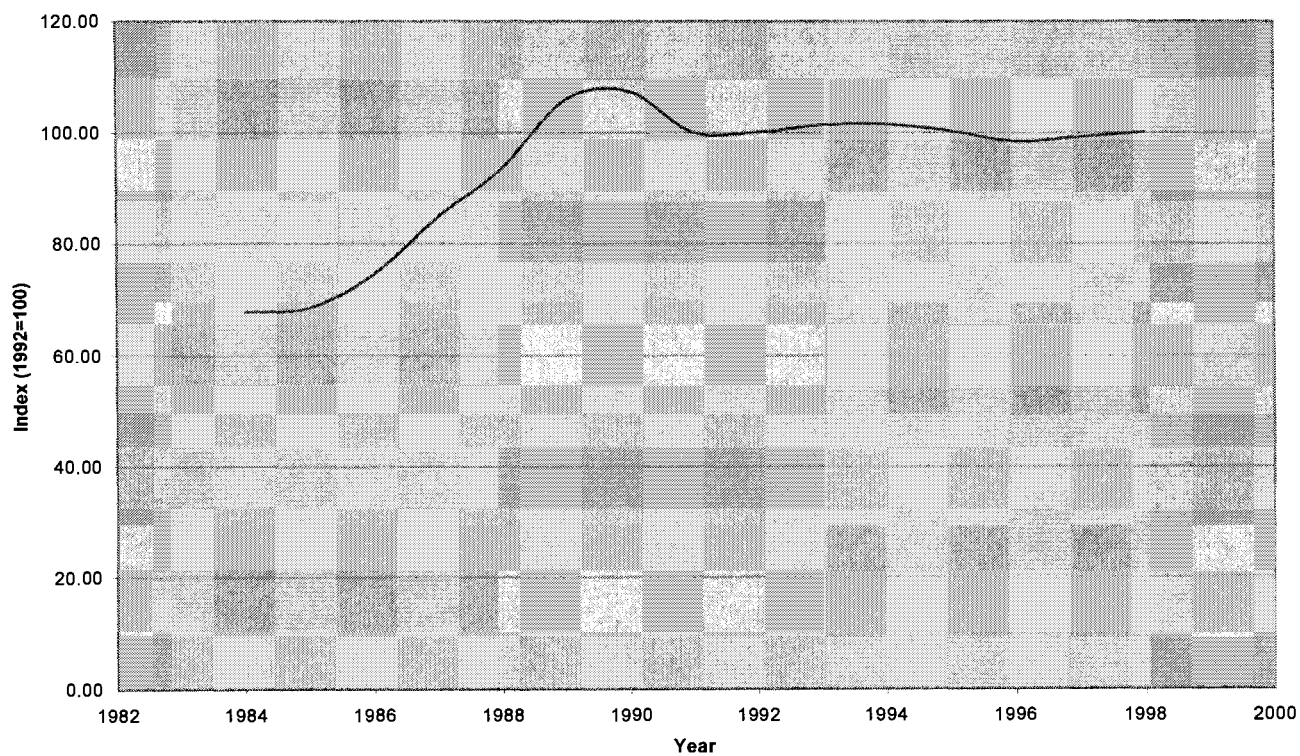
<sup>1</sup> Canadian Water and Wastewater Association (1997), *Municipal Water and Wastewater Infrastructure: Estimated Investment Needs 1997-2012*.



**Exhibit 1.1**  
**New Housing Starts**



**Exhibit 1.2**  
**New House Price Index**



**Box 1.1: Canada's Aging Sewer Infrastructure and Related Cost Issues**

**Miramichi (NB) Needs \$15 Million for Sewerage System** – Miramichi city council might send a memo to the federal Finance Minister, to bring his cheque book on his next visit. The Finance Minister announced in his budget a new program to put federal money into infrastructure projects across Canada - and Miramichi could use \$15 million to finish building its new sewage system as a result of the 1995 amalgamation. How long it will take to do this work depends on how much money the city can raise from the other two levels of government.

**Sudbury (ON) Sewage Woes May Freeze Development** – Widespread sewage backups are threatening to freeze development in Sudbury's south end - the city's fastest growing area - but the region's engineering committee has voted against further study of the problem. As a result the city may be facing a development freeze. The problem appears to be weeping tiles which surround many homes channeling rainwater away from dwellings and into sewers. Sewage flooded hundreds of homes in the city in 1989, 1990, 1994, and 1997 during intense rain or spring runoff.

**Toronto (ON) Sewerage Problems from Rainstorms** – Many of Toronto's sewage problems are caused by rainstorms, eaves troughs and the city's aging sewer system. Just one rainfall in early summer is usually enough to bring out "No Swimming" signs, particularly in the western beaches.

**Milton (ON) Pipe Dream Comes True (March 2000)** – The Big Pipe project is right on schedule, and water should be flowing into Milton by Sept. 29. The pipes are going to cost about \$27 million for the Oakville-to-Milton stretch of 15.5 kilometres. The \$27 million portion of the project is being entirely paid for by six developers in Milton who will benefit in the first phase of new housing development. Milton has not been able to allow any significant development for years because of a lack of water.

**Hamilton (ON) Aging Infrastructure Needs Upgrading** – A dollar per household per day: that's how much more Ontarians should be paying for water supply and sewage treatment to upgrade, replace and maintain the aging infrastructure in the province. According to a Toronto-based consultant, most people won't mind the extra costs if it means continued safe, clean water and a better environment. The consultant believes that homeowners should be paying about \$700 per year if staggering costs to rebuild the systems are to be avoided. The Ministry of Environment estimated that Ontario will have to spend \$15 billion over 15 years to upgrade infrastructure - \$13.5 billion of that for wastewater and \$3 billion for maintenance and upgrades to the system.

**Victoria (BC) Sewage Upgrade Costs Estimated at \$31 Million** – Victoria's Capital Regional District (CRD) residents face major sewer upgrade costs even without building a sewage treatment plant. Some \$7 million in repairs and upgrades has already been approved for this year, and an estimated \$30.7 million will have to be spent over the next five years, say CRD engineering staff. Aging infrastructure and new capacity needs are behind the upgrades.

Source: Extracted from year 2000 editions of the *CWWA Bulletin* prepared by the Canadian Water and Wastewater Association.

Furthermore, global climate change has the potential to change the frequency and severity of inland flooding, increasing the need for and costs of stormwater management infrastructure. General circulation models suggest that some regions may have more rainfall and more intense rainfall, increasing the number of basement flooding and other flooding events. Earlier snowmelt could also worsen spring flooding. As a consequence, costs to homeowners for funding stormwater infrastructure may increase as a result of global climate change.

In the past, the majority of stormwater management efforts were undertaken at the municipal level. Large, engineered solutions were planned and implemented that addressed stormwater across relatively large areas, certainly more expansive than individual neighbourhoods. For example, these include massive storm sewer systems, storage tanks, and treatment facilities. This approach has been criticized extensively for sometimes being unnecessarily costly and ineffective.

One alternative to large-scale, publicly management infrastructure that is increasingly being considered rests in stormwater management at the lot- or cluster- level. This approach, built upon stormwater best management practices (BMPs), relies on local, smaller-scale solutions. These BMPs have been considered because they have sometimes been viewed as lower cost and more effective solutions.

One barrier which has prevented more widespread uptake of on-site best management practices has been the level of information available to developers, architects, house builders, and government planners surrounding these BMPs. Limitations continue to exist with respect to both technical/scientific information and economic/financial information.

This study provides a foothold to overcoming these barriers to the Canadian housing industry.

## ***1.2 Terms of Reference***

This study will provide practical information to developers, landscape architects, and municipalities to promote stormwater best management practices (BMPs) at the level of the individual lot or a cluster of buildings. It will examine the costs and benefits of practical solutions as well as any barriers to implementation through a series of case studies.

Specifically, the study will:

- prepare case studies of lot- and cluster- level stormwater BMPs, including documentation of their key economic, technical, and implementation issues; and
- outline the key economic, technical, and implementation issues of other potential BMPs where relevant case studies are unavailable in Canada.

### ***1.3 Remainder of this Study***

The remainder of this Report proceeds as follows.

- Section 2 provides an overview of key stormwater management issues.
- Section 3 discusses traditional stormwater management financing options.
- Section 4 describes alternative lot- and cluster- level stormwater best management practices.
- Section 5 provides a high-level overview of BMP functions.
- Sections 6 through 16 provide descriptions of the ten stormwater best management practices, as well as effectiveness and economic analyses, and a discussion of implementation issues.

### ***1.4 Scope of Analyses***

The material presented herein is based largely on a published literature review. Information was primarily drawn from North American sources, but not always Canadian sources. As such, the descriptions of best management practices presented here are put forward as initial steps in moving towards the implementation of lot- and cluster- level BMPs. Each can come in different shapes and varieties. Developers, architects, builders, planners, and others should seek detailed information from qualified experts in deciding whether or not to move forward in implementing a stormwater BMP.

Furthermore, much of the costing information is based on U.S. experience and may not be perfectly transferable to Canada. At the same time, relatively little cost information is available. The initial and on-going costs of stormwater best management practices also tend to be very site specific, and considerable variability can exist among cost experiences. Developers, architects, builders, planners, and others should seek detailed information from qualified experts in determining BMP costs.

## 2 OVERVIEW OF STORMWATER MANAGEMENT ISSUES

### 2.1 *The Causes of Urban Stormwater Pollution*

Stormwater runoff has long been recognized as a significant contributor to environmental and socio-economic concerns in Canada. These concerns arise from the adverse quantity and quality impacts of stormwater runoff.

- *Stormwater Quantity Impacts* – Under natural conditions, only about 10% of rain water exists as runoff, with the remainder infiltrating soils or evaporating. In an urban setting with more impervious area, however, about 55% of rain water tends to exist as stormwater runoff.
- *Stormwater Quality Impacts* – Stormwater also has adverse quality impacts through contaminants collected during runoff. In urban areas, contaminants depend largely on surrounding land uses. In rural areas, pesticides and fertilizers are particular concerns.

#### *Stormwater Quantity*

The amount of stormwater runoff depends on, among other realities, the amount of impervious surface area. The natural and built environments both include a mix of pervious, semi-pervious, and impervious areas. Land development and human activity tend to increase the amount of impervious area. Human activities compact the surface soil, while human-made structures (primarily for housing and transportation) increase impervious area. The increased impervious area, in turn, contributes to a variety of stormwater related concerns, including:

- increased volume of runoff;
- greater stream and runoff velocity during storm events;
- increased peak discharges; and
- reduced groundwater recharge.

#### *Stormwater Quality*

The second aspect of urbanization that contributes to urban stormwater pollution is the increased uptake and discharge of pollutants. The primary urban activities contributing to the increased discharge of pollutants include:

- |                            |                                     |
|----------------------------|-------------------------------------|
| ▪ construction operations  | ▪ landscaping activities            |
| ▪ pest management          | ▪ operation of landfills            |
| ▪ littering                | ▪ pet and animal waste              |
| ▪ vehicle use              | ▪ transportation de-icing           |
| ▪ sewer cross-connections  | ▪ poor septic systems               |
| ▪ outdoor material storage | ▪ releases from industrial activity |

In short, human activity and structures can reduce the quality of stormwater runoff.

## 2.2 *The Consequences of Urban Stormwater Pollution*

The degradation caused by urban stormwater quantity and quality concerns is a serious economic, environmental, and social issue that impacts upon a significant proportion of the population.

- *Flooding and Personal Property Damage* – Flooding and damage to personal property, residences (including basement flooding), and commercial/industrial properties represent the most visible consequence of the increase in the volume and rate of stormwater runoff.
- *Infrastructure Damage* – Stormwater runoff can damage physical infrastructure, including streets, highways, and bridges. The costs of this damage are eventually passed-back to the homeowner in the form of higher taxes.
- *Streambank and Streambed Erosion* – The increased volume and rate of urban stormwater runoff erodes streambanks and streambeds, dislodging and suspending sediment that may have otherwise remained in place.
- *Siltation and Sedimentation* – Rapidly flushing stormwater increases erosion, and stormwater then transports the eroded sediment downstream into receiving waters. Once the sediment-laden water is stilled, the sediment settles to the bottom of the stream.
- *Increased Water Temperature* – Water that infiltrates the ground and flows beneath the surface is usually much cooler than surface runoff. In addition to preventing infiltration, impervious surfaces also often warm runoff.
- *Harm to Aquatic Life* – Urban runoff can harm aquatic life in many ways due to changes in water chemistry and habitat loss. Both the increased volume and velocity, and the increased discharge of pollutants, contribute to this change in chemistry and habitat loss.
- *Harm to Sport Fishing* – Harm to sport fishing is a direct result of the harm to fisheries. In many locations across Canada sport fishing is a big business, and many of the species that anglers prize are those most sensitive to degraded water conditions.
- *Human Health Effects* – Stormwater carries disease-causing bacteria, viruses, and protozoa. Studies document that extensive human health effects that can result from contact with stormwater-polluted waters, including contact through swimming.
- *Impacts to Drinking Water Supply* – In urbanized areas, pollution from stormwater has become a serious concern in respect of water supplies. In such cases, increased costs are borne for drinking water treatment, again eventually paid for by the consumer.
- *Aesthetic Effects* – Cigarette butts, polystyrene cups, and other trash that storm sewers dump into neighbourhood water are eyesores. In addition, sediment loads reduce the clarity of the water, reducing its attractiveness and the value of economic businesses relying on the water.

As a whole these adverse quantity and quality impacts of stormwater lead to a less valuable environment and a less prosperous economy. They also increase the costs of building and owning a home.

### 3 TRADITIONAL FINANCING OPTIONS AT THE MUNICIPAL AND LOT LEVELS

Traditionally, municipal governments have relied on several mechanisms to collect revenues from home and business owners to manage stormwater. This section presents a brief discussion of the four mechanisms which have typically been employed to fund stormwater management projects and programs:

- property taxes;
- water rates and sewer surcharges;
- development charges; and
- user charges.

Grants and subsidies from the federal and provincial government played a role in funding municipal stormwater management programs in the past, but are unlikely to do so in the future due to growing constraints on spending. As such, the problem has devolved to the municipal level, with municipal authorities searching for new and innovative solutions such as lot- and cluster- level BMPs.

#### *Property Taxes*

Property taxes are paid by most property owners on the assessed value of land. Property taxes are determined by multiplying a mill rate (i.e., the tax rate levied per \$1,000 of assessed value of real property and business) by an assessed value. Different mill rates exist for residential and commercial properties, and for public and separate school supporters.

Revenues from property taxes are managed in funds, usually the "general fund" (i.e., the fund which records the costs and revenues of various activities conducted by city departments). Through these revenues, large municipal stormwater management projects -- usually referred to as "engineered solutions" -- have been funded. A single such project might support stormwater management for a large portion of a community rather than for an individual property.

#### *Water Rates and Sewer Surcharges*

Water and sewer rates/surcharges are charged by municipalities based on consumption of water or use of sewer services. Water consumption can be:

- measured (using water metres); or
- unmeasured (based on characteristics of the consumer).

For example, metered water users might pay \$1.00 per cubic metre of water consumed. Alternatively, unmetered users might pay \$20 per room per house annually. These water rates cover a portion of the cost of treating and distributing clean water, of collecting and treating wastewater, and sometimes of stormwater management.

Similarly, sewer surcharges can be levied as a portion of the water rate or accounted for as a separate entity. For example, water consumers might pay per cubic metre of water consumed, which includes an implicit sewer surcharge. Alternatively, each might pay an explicit sewer surcharge as a percentage of the water rate or as a flat rate. A portion of this sewer surcharge might be made available for municipal stormwater management projects and programs.

### ***Development Charges***

Development charges are charges paid by developers of new or expanding properties, residential or commercial. The charges are put in place to support some capital costs of new developments (for example, construction of storm and sanitary sewers, roads and sidewalks, libraries and sports facilities, electricity supply, etc.). In general, one development charge would be paid for a new or expanding property, with a portion of the revenues allocated as needed to various uses, possibly including the construction of municipal storm sewers.

Development charges can take a number of forms. Charges can be based on property areas (e.g., \$4.00 per m<sup>2</sup> of property), floor areas (e.g., \$10 per m<sup>2</sup> of floor), or frontages (e.g., \$100 per metre of frontage). Charges typically vary between residential developments and non-residential developments. These charges have been justified as being a "fair" means of supporting the costs of new development, though they have by no means been widely accepted (see **Box 3.1**).

### ***User Charges***

User charges are payments made by individuals for use of public infrastructure or services. In the stormwater context, user charges can be levied to recover the costs of public stormwater infrastructure and programs. Property owners would pay these charges, since developed properties and the built environment impose the need for public stormwater management by altering the natural hydrology.

In recent years, a wide and sometimes surprising range of user charges have been introduced in Canada. For instance, user charges are paid when entering national parks, when dialling 911, or for obtaining a passport. Sometimes these charges are highly visible (for example, when driving on a toll highway). In other instances, users of infrastructure and services might not recognize that a user charge has been paid (for example, a small user fee is paid as part of airline tickets for travel through some Canadian airports).

In Canada, user charges are typically justified on the grounds that those who use a service should pay for the service. User charges shift the burden of payment from the tax-paying public to the users of specific infrastructure and services. Some notable exceptions remain (i.e., many healthcare services and police protection). In addition, user charges are promoted since they generate a stream of revenues for a particular purpose (in other words, the user charges can be "earmarked"), such as local stormwater management.

Reliance on user charges for stormwater management in Canada is limited. The City of Regina has had a system of user charges in place since 1992 (see **Box 3.2**), and other municipalities are examining user pay options.



**Box 3.1: Development Charges**

In Canada, approximately half of the provinces and territories have legislation specifically dealing with development charges (sometimes called "lot levies"). In instances where there is no legislation surrounding development charges, provincial planning acts enable municipalities to require developers to build infrastructure within subdivisions to specified standards.

In Ontario, The *Development Charges Act* (1991) gives Ontario municipalities the right to impose charges on developers to help pay for infrastructure and service needs arising from new developments. The original Act included provisions allowing for cost recovery for roads, water and sewer systems, recreational centres, parks, libraries, cultural centres, and administrative buildings needed to accommodate new residents and businesses.

In the case of stormwater management, the initial cost of the development charge is born by the developer at the time of subdivision approval or the issuance of the building permit. However, a portion of this burden is passed through to the pre-development landowner, the builder, and the homebuyer in the form of higher costs.

At least five arguments in opposition to development charges have been raised.

1. Some groups argue that existing homeowners tend to receive a windfall benefit as their property values increase despite the fact that they do not pay the development charge. The members of the development chain, including new homebuyers, finance this windfall.
2. Development charges and property taxes are alternative means for borrowing. However, in the case of property taxes, governments usually borrow and recoup their debt through taxation. In the case of development charges, it is the developer/builder, and homebuyer who borrow. Since the government can borrow at a lower rate, development charges are argued to be an inefficient means of achieving a given objective.
3. In terms of accountability, new homebuyers pay the charge before moving into the neighbourhood. Consequently, new homebuyers cannot register opposition to these charges prior to paying the charge.
4. Development charges have also been criticized for their impact on land use. It is generally more expensive to service a low-density area than a high-density area. However, average costs recovered through development charges are often applied uniformly. In this way, development charges encourage over-development of low-density areas and under-development of high-density areas, contributing to urban sprawl.
5. Finally, it has been argued that development charges increase the price of housing and in this regard, discourages new development. This naturally raises the question of what the impacts of development charges are on the housing industry, and whether these are fair and equitable.

Source 1: Ontario Ministry of Municipal Affairs and Housing (1996), *Background Information -- The Development Charges Act, 1996*.

Source 2: Enid Slack (1994), *Development Charges in Canadian Municipalities: An Analysis*.

**Box 3.2: The User Pay Approach to Stormwater Management**

The City of Regina employs user charges for funding stormwater activities, an alternative mechanism not seen in Metro Toronto or other major Canadian municipalities. In 1992 user charges were introduced, with charges based on total property area. Typical residential charges are in the range of \$3.50 per month, distributed on bi-monthly water and sewer bills. Non-residential user charges of \$18.80 per month would be levied on a 20,000 m<sup>2</sup> industrial property.

In the U.S., over 100 municipalities have implemented user pay approaches to stormwater management. Widely available statistics show that these programs have characteristics as follow:

- 75% of monthly residential stormwater management fees are in the range of US\$1-\$4;
- 60% of user charge programs are based on estimates of impervious property area; and
- 65% of programs are administered by utilities, and 35% by public works departments.

For example, assuming an average monthly user pay bill of C\$4.00 per household and 50,000 households, nearly \$25 million could be dedicated for stormwater management purposes over a ten year period. Note that at several U.S. municipalities have monthly residential user fees in the range of US\$10 or more.

***Financing BMPs***

In general, structural BMPs tend to involve the construction of facilities at the time of development. These facilities are established and paid for by a developer/builder, perhaps as a condition for the development to occur. Ultimately, these capital costs are passed through to homeowners as homes are purchased and sold/resold.

Stormwater BMPs also come with on-going costs in terms of operations and waste disposal. These costs may initially be planned for by the developer/builder, and recouped as a one-time charge to home buyers. Actual long-term maintenance may then be contracted to stormwater facility specialists and perhaps be monitored by a municipality. In some cases few mechanisms may exist other than for property owners to voluntarily undertake the maintenance and disposal activities themselves. This reality may limit the ongoing effectiveness of some lot- and cluster-level BMPs.

When a stormwater BMP is implemented, the actions of the developer, builder, and property owner have reduced the need for publicly owned and operated stormwater management infrastructure (i.e., storm sewers, treatment plants, etc.). Despite these actions and their associated costs, traditional financing options may nonetheless continue to recover (through taxes, water surcharges, etc.) payments from these property owners.

## 4 LOT- AND CLUSTER- LEVEL STORMWATER BMPs

### 4.1 Stormwater BMPs Defined

Beyond the conventional engineered solutions to municipal stormwater management (supported by property taxes, water and sewer surcharges, development charges, and user charges), lot- and cluster- level best management practices financed by the developer, builder, and homeowner also exist. At the broadest level, these stormwater best management practices are sub-divided into two categories:

- structural BMPs; and
- non-structural BMPs.

This report focuses on structural BMPs, given that these are most relevant for the developers and builders. Non-structural BMPs could be employed by home and business owners to further reduce stormwater demands on public infrastructure.

#### *A Word of Caution*

The locations available for on-site BMPs and the suitability of specific BMPs depends largely on the physical character of the site (primarily the infiltration capacity), the type of land use, and the development form. Planning measures such as lot configuration and building envelope often determine the "implementability" of different measures. By the same token, site-specific considerations determine the costs of lot- and cluster- level BMPs.

On-site controls can be located on the building or ground surface and below ground or beneath a building. They can be placed in front or rear yards, below or along side the road, in cul-de-sacs, medians or in round-about islands.

There are a variety of opportunities and constraints for the application of on-site stormwater controls. Different BMPs can address water quality and quantity control or a combination of these. There are often limitations however. Available techniques may be most applicable to only residential or commercial/industrial land uses, they may address only water quality or water quantity or they may be applicable only with certain soil conditions.

They may need to be coupled with downstream end-of-pipe controls or combined with other on-site controls in series (in an effort to increase their effectiveness). Maintenance and continued operation of lot-level controls can also be a concern in residential development because the owner (or subsequent owners) may remove or otherwise alter the control, reducing or eliminating its effectiveness.

## 4.2 *Inventory of Structural BMPs*

Structural BMPs involve physical plant and modification of the environment. Structural BMPs may be above ground, at-level, or below ground; can range from small devices to larger facilities; and can often be installed in either greenfield or brownfield developments.

**Bioretention Filters** – Bioretention is a water quality practice in which plants and soils remove pollutants from stormwater naturally. Bioretention filters are similar to conventional surface filters, but they allow the integration of open space and landscaping areas with the stormwater management facility.

**Constructed / Artificial Wetlands** – Constructed wetlands consist of environments that have been modified to create drainage soil and wetland flora and fauna for the purposes of runoff containment and pollutant removal. Physical, chemical, and biological water quality treatment of stormwater runoff is provided where a continuous baseflow exists.

**Curb Elimination** – Curb elimination reduces pollution entering the aquatic environment through the elimination of curbs. Because curbs function as a channel for stormwater runoff carrying sediment and other pollution, eliminating curbs allows runoff to be spread over large vegetated areas where velocity can be reduced and pollutants can settle.

**Detention Ponds / Dry Ponds** – Detention ponds are basins that temporarily store a portion of stormwater runoff following a storm event. Generally, these ponds do not have a permanent water pool between storm events – water is discharged by overflow, through pipes, by evaporation/transpiration, by infiltration or by some combination of these methods.

**Filter Strips / Vegetative Buffer Strips** – Filter strips are typically bands of close-growing vegetation, usually grass, planted between pollutant source areas and a receiving water. Such strips are used primarily in residential areas around streams or ponds. The two general types of strips are grass filter strips and forested filter strips.

**Grassed Swales** – Grassed swales are shallow vegetated channels used to convey stormwater. Pollutants are removed by settling, filtration through grass and infiltration into the soil. Requirements include shallow slopes and soils that drain well. Grassed swales are generally associated with rural drainage because of area and slope requirements.

**Infiltration Basins** – Infiltration basins are above-ground pond systems that are constructed in highly pervious soils. Water infiltrates the basin and either recharges the groundwater system or is collected by an underground perforated pipe network and discharged to a downstream outlet. Generally, these are used for larger drainage areas than infiltration trenches.

**Infiltration Trenches** – Infiltration trenches are lined with a filter (fabric) and backfilled with stone to form an underground basin. Runoff is diverted to the trench and either exfiltrates into the soil, enters a perforated pipe underdrain, or is routed to an outflow facility. Smaller trenches are used for quality control, while larger trenches are used for quantity control.

**Oil and Grit Separators/Water Quality Inlets** – Oil and grit separators are typically two or three chamber structures designed to remove sediment, oil, grease and large particulates from stormwater. Generally, outflow is routed to the storm drain system. Numerous variations of oil and grit separator exist, however, their use is normally limited to industrial sites.

**Pervious Pipe System** – Pervious pipes are perforated along their length and allow exfiltration of water through the pipe wall as the stormwater is conveyed downstream. The pipe itself is similar to that used for tile drainage on agricultural lands and is available with either a smooth-walled or corrugated interior.

**Porous Pavement** – Porous pavement is an asphalt or concrete based paving material that allows stormwater to infiltrate the surface pavement to enter into an aggregate sub-base layer. The captured runoff is stored in this reservoir until it either infiltrates into the underlying soil, or is routed through a perforated underdrain system to conventional storm sewers.

**Reduced Lot Grading** – Reduced lot grading reduces the slope of the land surrounding a home, reducing the amount of runoff that flows across the surface, and promoting natural filtration. The benefits of this strategy can be extended if surrounding soil is tilled prior to laying sod to prevent excess compaction.

**Retention Ponds / Wet Ponds** – Retention ponds are basins that incorporate a permanent volume of water in their design, and temporarily slow stormwater flows. Several mechanisms in wet ponds remove pollutants including settling of suspended particles, biological uptake or consumption of pollutants, and decomposition of some pollutants.

**Roof Leader Disconnection** – Roof leader disconnection involves disconnecting downspouts and extending roof leaders to ponding areas or infiltration trenches. Water is detained in the ponding area until it evaporates or infiltrates, or in the infiltration trench until it infiltrates. This technique can be implemented as a natural extension of reduced lot grading.

**Sand Filters** – Sand filters are stormwater control devices used to treat stormwater runoff from large buildings, access roads, and parking lots. Sand filters remove sediments and pollutants from the first flush volume of pavement and impervious area runoff. A mat of bacterial "slime" typically enhances the filtration of nutrients, organics, and bacteria.

**Sump Pumping of Foundation Drains** – Sump pumping of foundation drains uses a sump pump to discharge foundation drainage to either the surface or soakaway pits. Either of these two methods is preferable to the connection of the foundation drains to the storm or sanitary sewer, since foundation drainage is relatively clean water.

**Urban Forestry** – Urban forestry relies on tree planting and placement to help manage stormwater. Trees decrease the amount of surface overflow and absorb runoff. Careful consideration to tree placement is required to intercept runoff, and ensure that volume of runoff doesn't overwhelm the capacity of existing trees.

### ***4.3 Inventory of Non-Structural BMPs***

Non-structural best management practices for stormwater rely on "practices" rather than micro-infrastructure, and are described below. These BMPs cannot be introduced by developers or builders, only by residential, commercial, and institutional building owners.

**Animal Waste Collection** – Animal waste collection involves the control of animal waste through by-laws that require the collection and removal of waste from curbsides, yards, parks, roadways and other areas where the waste can be washed directly into receiving waters. By-laws can be also be expanded to industries that spread animal waste on fields.

**Chemical Storage** – Chemical storage protects certain materials from exposure to rainfall and runoff to avoid leaching of contaminants and discharge to surface waters. Industrial properties, vehicle maintenance and storage areas, fueling areas and gasoline stations, parking areas, weigh stations and food service areas are of particular concern.

**Educational Programs** – Educational programs attempt to improve the quality of water through education. Government agencies can sponsor programs to educate citizens on proper disposal of litter, yard waste, used motor oil, and other household wastes. Likewise, industry can learn to properly dispose of industrial wastes through in-house training and interactive seminars.

**Exposure Reductions** – Exposure reduction improves stormwater quality by reducing or eliminating exposure of materials that are potential pollutants to runoff. Typical strategies in residential areas involve moving or covering potential pollutants, while industry can use just-in-time delivery and covered storage to minimize the time materials are exposed.

**Illicit Discharge Controls** – These are various controls aimed at preventing the storm sewer system from being used as an inexpensive or convenient alternative to the proper disposal of wastewater and fluids. Illicit dumping controls may include storm drain labeling, personal training, increased public awareness, and investigation of reported complaints.

**Landscaping and Vegetative Practices** – Landscaping and vegetative practices utilize various forms of vegetation to increase landscape roughness, helping control both the quantity and quality of stormwater runoff. Vegetative practices can be an effective means of pre-treatment to reduce the magnitude and cost of other stormwater management.

**Parking Lot / Driveway Cleaning** – Parking lot cleaning involves the regular cleaning of parking lots to reduce pollutants that may enter runoff. In addition to the direct improvement in stormwater quality, this also reduces the likelihood that pipes and outlets in detention structures and ponds will become clogged.

**Pesticide and Fertilizer Management** – Pesticide and fertilizer management improves stormwater quality by reducing the amount of pesticides and herbicides in runoff. Chemicals are applied in a timely manner, in only the types and amounts necessary. Another option includes utilizing an Integrated Pest Management Approach (IPM) to reduce chemical needs.

**Street / Sidewalk Sweeping** – Street and sidewalk sweeping are non-structural BMPs that can be undertaken by municipal departments or concerned homeowners. Street and sidewalk sweeping can remove particulate matter from impervious surfaces before it is swept up in stormwater.

## 5 OVERVIEW OF BMP FUNCTIONS

Stormwater management needs to address multiple objectives including:

- water quality control;
- peak flow control;
- erosion control;
- water balance control; and
- special purpose control.

On-site controls are a necessary part of effective stormwater management, for all the objectives noted above and to reduce the cost of infrastructure and end-of-pipe controls. Most BMPs, however, cannot achieve these five objectives alone. For this reason, several on-site BMPs are often coupled together or, are used in conjunction with downstream end-of-pipe controls, an approach known as a "treatment train".

### 5.1 *Water Quality Controls*

Other than the infiltration measures discussed below (under water balance), there are relatively few purely water quality measures which are applicable to residential land uses. Filter strips or bioretention filters used in conjunction with rear-yard swales do produce water quality benefits.

In commercial/industrial areas, various forms of sand filters (parking lot perimeter filter, basement filter) bioretention filters, and oil/grit separators can be employed. Filters benefit from the use of pre-treatment devices (eg., storage elements or oil/grit separators). Bioretention filters (a constructed "natural" island, with a sand diaphragm and bottom, and an under-drain system) allow water quality treatment to be combined with landscaping. Pocket infiltration, pocket wetlands, and bioretention filters can be incorporated into the road allowance. Each would typically be located in cul-de-sacs, islands, or in median strips and would treat only a small drainage area. They are best used as part of an area wide stormwater approach that specifically seeks opportunities for implementation.

Subsurface filtration techniques (variations on pervious pipe systems) may be employed under roadways in areas where the soils do not support infiltration. Water is discharged from catchbasins to an underground filter layer and the filtered water is collected by a perforated storm sewer pipe. This technique is expensive as a retro-fit measure but has scope in new development and in areas where road reconstruction or sanitary sewer upgrades are required.



## ***5.2 Peak Flow Controls***

Peak flow control is primarily practiced as an end-of-pipe measure aimed at preventing flooding. Local controls are most often implemented in an effort to reduce the cost of downstream infrastructure (storm sewer pipes and detention facilities). Commercial and industrial areas receive the greatest attention in this regard because of their high imperviousness and the availability of flat roofs and parking lots. In residential areas, storage for extreme runoff events can be provided in rear yard swales or on streets by restricting the amount of flow which can enter the sewer system.

## ***5.3 Erosion Controls***

A useful set of erosion control techniques for residential areas involves the capture and storage of roof runoff for future re-use. Storage devices include cisterns, rain barrels or contained planting areas (eg., storm gardens on rooftop terraces). Historically, rainwater stored in cisterns has been used for laundry because of its “soft” nature. Water re-use techniques remove water from the system (typically converting runoff to evapotranspiration). This may be undesirable in some areas, especially where the baseflow in watercourses is a concern. In commercial/industrial settings there is sometimes sufficient space that dry ponds can be used to reduce discharges from the more frequent storm events. This however is an exception, rather than the rule in most urban areas.

## ***5.4 Water Balance Controls***

In areas with soils having an adequate infiltration potential the preferred approach is to use any of a variety of passive or active infiltration techniques. Runoff that is infiltrated aids in erosion protection, water quality control and to a limited extent, peak flow control, in addition to the primary function of maintaining the water balance. In residential areas, many passive measures aimed at simply retaining runoff on the ground (so it can soak in or evaporate) are employed. In areas with sandy (high infiltration capacity) soils, more concentrated infiltration techniques such as soak-away pits or infiltration trenches can be employed.

In commercial/industrial areas and road right-of-ways, concentrated techniques are normally used because of the amount of impervious surface. Perimeter swales or linear swales between parking rows or in the road allowance can be used, as can infiltration trenches. Subsurface infiltration techniques may be employed under parking lots or roadways. In one particular system (the Etobicoke system) water is discharged from catchbasins to a small diameter pervious pipe which is plugged at one end. The runoff exfiltrates from this pipe, up to the soils’s capacity. The pervious pipe is connected to the regular storm sewer system so that if too much runoff occurs the water backs up from the pervious pipe into the regular storm sewer.

The use of infiltration techniques may be restricted in areas where the groundwater is used for water supply. Infiltration of roof runoff is usually acceptable but salt and dissolved metals from road ways can contaminate drinking water supplies. Application of salt should be limited in all areas using infiltration techniques because the salt can build up, changing the properties of the soil and reducing its capacity for infiltration.

### ***5.5 Special Purpose Controls***

Special purpose controls are used to address specific concerns such as oil spills for land uses that are at high risk (eg. gas stations, truck or bus cleaning stations, etc.). They can also be useful in commercial parking areas where oils and grease tend to accumulate on the pavement surface.

There are numerous proprietary special purpose controls, the most common category of which is generically referred to as oil/grit separators. These devices are effective against oil products and, as their name implies, are also capable of removing coarse sediment. However, as with other non-infiltration controls, their sediment removal capability often falls below that which is recommended for a stand alone water quality control. As a result, they are best used in series with other local water quality controls or in conjunction with end-of-pipe controls, if their role is to extend beyond spill control to water quality protection.



## 6 CASE STUDIES OF ON-SITE STORMWATER BMPS

Ten "case studies" of on-site stormwater best management practices were conducted, as shown in **Exhibit 6.1**.

**Exhibit 6.1**  
**Stormwater BMP Case Studies**

<b>Case Study</b>	<b>Stormwater Best Management Practice</b>
1.	Constructed Wetlands
2.	Detention Ponds
3.	Downspout Disconnection
4.	Infiltration Trenches
5.	Oil and Grit Separators
6.	Porous Pavement
7.	Retention Ponds
8.	Sand Filters
9.	Urban Forestry
10.	Vegetative Practices

These case studies are found in the following sections.

## 7 CONSTRUCTED WETLANDS

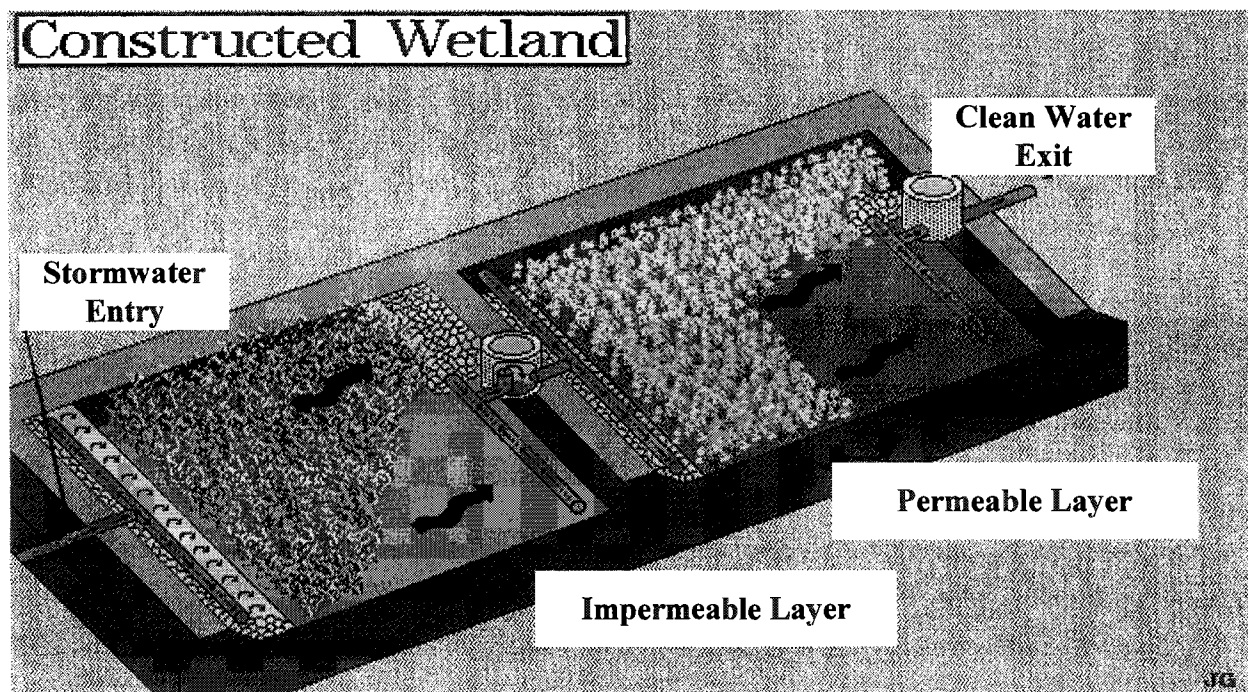
### *Description*

Constructed wetlands are shallow pools developed specifically for storm or waste water treatment that create growing conditions suitable for wetland plants. Constructed wetlands differ from other artificial wetlands in that they are not typically intended to replace all of the functions of natural wetlands. Rather, they are designed to provide water quality benefits by minimising point source and nonpoint source pollution prior to its entry into streams, natural wetlands, and other receiving waters. They can also play a water quantity management role.

There are two basic types of constructed wetlands:

- subsurface systems have no visible standing water, and are designed so that the wastewater flows through a gravel substrate beneath the surface vegetation; and
- surface flow systems have standing water at the surface and are more suited to larger constructed wetland systems such as those designed for municipal wastewater treatment.

The following exhibit illustrates a “two-cell” constructed wetland involving an impermeable cell and permeable cell.



Source: Revised from <http://www.marshlands.com/lissom.htm>.

Enhanced constructed wetlands can also be designed for more effective pollutant removal. They include design elements such as a forebay, complex microtopography, and pondscaping with multiple species of wetland trees, shrubs and plants.

### *Effectiveness Analysis*

Constructed wetlands can be used to manage stormwater runoff peak discharges and make modest reductions in overall runoff quantity. Quantity reductions can be achieved through infiltration of stormwater to the water table, and some delays in peak flows.

Stormwater quality management is typically the reason why constructed wetlands are considered as a stormwater management facility. Properly constructed and maintained wetlands can provide very high removal rates of pollutants from stormwater. Removal of pollutants is accomplished through adsorption, wetland plant uptake, retention, gravitational settling, physical filtration and microbial decomposition, thus improving runoff quality.

Among the most important pollutant removal processes are the purely physical processes of sedimentation and filtration by aquatic vegetation. These processes account for the strong removal rates for suspended solids, organic matter (particulate BOD), and sediment-attached nutrients and metals. Similarly, pathogens show good removal rates in constructed wetlands through sedimentation and filtration, natural die-off, and UV degradation.

Dissolved pollutants such as soluble organic matter, ammonia and ortho-phosphorus tend to have lower removal rates. Removal rates for metals are variable, but are consistently high for lead, which is often associated with particulate matter. Constructed wetlands can be expected to achieve or exceed the pollutant removal rates estimated for wet pond detention basins and dry detention ponds.<sup>2</sup>

Published ranges of removal for various pollutants are given below.

Pollutant	Removal Efficiency
Plant Nutrients	
Total Phosphorus	High
Total Nitrogen	Moderate
Sediment Suspended Solids	Very High
Trace Metals (Sediment-Bound)	High
Organic Matter Biochemical Oxygen Demand	Moderate
Oil and Grease	Very High
Bacteria	High

Source: Compiled from Schueler 1987; Schueler, et al. 1992; US EPA 1990; Phillips 1992; Birch, et al. 1992 and others.

Actual pollutant removal rates depend on the aquatic treatment volume, the surface area to volume ratio, the ratio of wetland surface area to watershed area, and plant types. Additionally, longer stormwater flow paths through the wetland and longer detention times within the wetland are expected to improve pollutant removal rates.

<sup>2</sup> See <http://h2osparc.wq.ncsu.edu/descprob/urbstorm.html>.

### *Economic Analysis*

The cost of establishing a constructed wetland varies depending on size and site conditions. In general, larger constructed wetlands involve higher construction, installation, maintenance, and waste disposal costs. Some sources suggest that constructed wetlands, for the storm and/or waste water they treat are relatively inexpensive, with the costs of a constructed wetland intended to serve a cluster of houses similar to installing a conventional septic system.<sup>3</sup>

Several estimates of the costs of constructed wetlands have been published:<sup>4</sup>

- *Construction Costs* – Using data from municipal systems, Kadlec (1995) cites construction costs from 18 North American surface flow wetlands ranging from \$6,000 to \$300,000 per hectare (1994), with a mean of \$100,000. Reed et al. (1994) cited a range of \$100,000 to \$240,000 per hectare for the same type of system.
- *Operations and Maintenance Costs* – Once established, the operation and maintenance costs for constructed wetlands can be lower than for alternative treatment options, generally less than \$1,500/ha/year (Kadlec, 1995), including the cost of pumping, mechanical maintenance, and pest control.

Details on the size and features of these constructed wetlands are unavailable.

### *Implementation Issues*

Wetlands may be highly valued by homeowners, and can therefore serve as centerpieces to developments and recreational areas.

- *Site* – Constructed wetlands can be applied to most development situations where sufficient baseflow is available to maintain water elevations. To maintain a constant water level, it is often necessary to have a reliable dry-weather baseflow source or groundwater supply.
- *Soils* – It is difficult to establish wetlands at sites with sandy soils or other soils with high infiltration rates. A careful review of local climate and water table conditions should be conducted before choosing this BMP.
- *Climate* – Constructed wetlands can be adapted for most regions of the country that are not excessively arid. Constructed wetlands have been effective in treating wastewater as far north as the Northwest Territories and the Yukon.
- *Thermal Pollution* – The standing water in constructed wetlands may contribute to thermal pollution and contribute to downstream warming. This may preclude the use of this BMP in areas where sensitive aquatic species live.

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<sup>3</sup> See <http://www.marshlands.com/faq.htm>.

<sup>4</sup> See <http://h2osparc.wq.ncsu.edu/info/wetlands/manage.html>.

- *Safety* – Both natural and constructed ponds are attractive play areas for children. A shallow "safety bench" around the edge of a wetland and/or dense vegetative growth around the perimeter to limit access may ease some safety concerns in urban areas.
- *Maintenance* – Constructed wetlands have an establishment period during which they require regular inspection to monitor hydrologic conditions and ensure aquatic, shoreline, and upland plants are surviving. Wetland operators may need to control nuisance insects, odours, and algae.

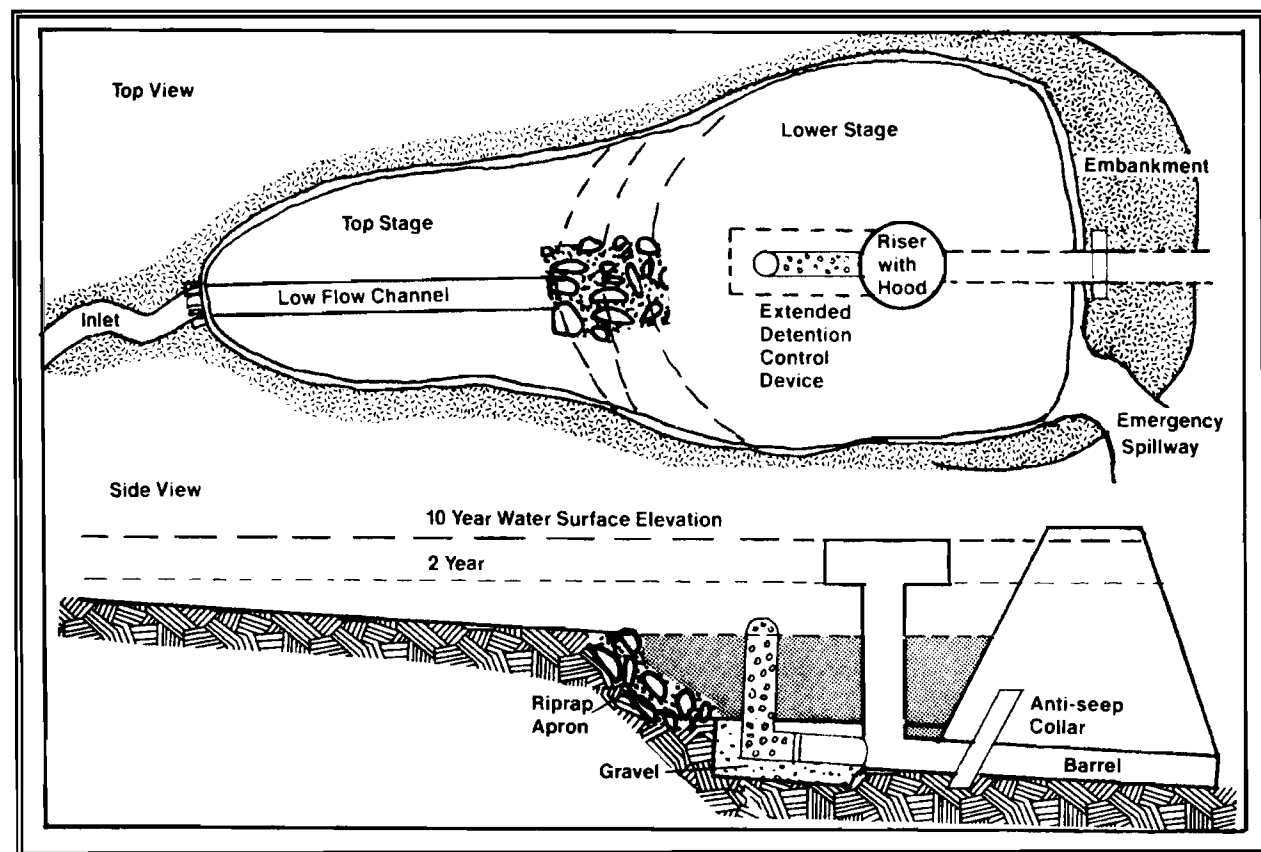


## 8 DETENTION PONDS

### *Description*

Detention ponds temporarily delay a portion of stormwater runoff for a length of time, controlling the release of the stormwater to reduce flooding and remove a limited amount of pollutants. They are also referred to as “dry ponds” because these facilities do not maintain a permanent pool of water between rainfall events.

A schematic of an extended detention pond is provided below. The “extended” variation means the pond is designed to drain more slowly than a simple detention pond, and therefore holds a pool of water for a longer period of time.



Source: Schueler, T. (1987), *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*.

A further variation of the detention pond and extended detention pond is the enhanced extended detention pond. These ponds include a sediment forebay near the inlet, a micropool and/or plunge pool at the outlet. They provide greater flexibility in achieving target detention times, which are a key determinant of pollutant removal efficiency and flow controls.

### *Effectiveness Analysis*

Dry ponds provide some water quantity and some water quality benefits.

Detention ponds do not reduce the total volume of stormwater, except through a small amount of infiltration and evaporation. They do, however, reduce the quantity of peak storm runoff flow by holding stormwater in a pool and delaying its discharge. These peak flow benefits require detailed stormwater management models to estimate.

Detention and extended detention ponds have proven effective at improving runoff water quality by removing particulate pollutants through gravitational settling. However, the overall pollutant removal in dry detention ponds is low to moderate compared to other stormwater management facilities. Negligible removal of soluble pollutants (such as salt) is provided.

<b>Pollutant</b>	<b>Removal Efficiency</b>
Plant Nutrients Total Phosphorus Total Nitrogen	Low Low
Sediment Total Suspended Solids	High
Metals Lead Zinc	Moderate to High Moderate
Organic Matter Biochemical and Chemical Oxygen Demand	Moderate
Oil and Grease	Low
Bacteria	High

Source: Compiled from Schueler 1987; Schueler, et al. 1992; US EPA 1990; Phillips 1992; Birch, et al. 1992 and others.

### *Economic Analysis*

Four main cost categories are associated with the acquisition and operation of a detention pond:

- one-time capital costs;
- one-time installation costs;
- recurring maintenance costs; and
- recurring waste disposal costs.

All four categories vary according to the size of the pond, under the following guidelines for simple detention ponds.

Cost Category	Type of Cost	Price	Unit
Capital Costs	Low-Flow Channel	\$60	m
	Rip Rap, Low-Flow, Outlet, Spillway	\$60	m <sup>2</sup>
	Riser with Hood	\$1,800-\$7,200	n/a
	Detention Orifice with Cap (300 mm)	\$500	m
	Outlet Pipe (Concrete, 450 mm)	\$2,400	m
Installation Costs	Excavation	\$12	m <sup>3</sup>
	Earthworks	\$4	m <sup>3</sup>
	Vegetation	\$1	m <sup>2</sup>
Maintenance Costs	Landscaping	\$2	m <sup>2</sup>
	Silt/Sediment Removal (Every 5 Years)	\$1	m <sup>2</sup>
	Removal Labour	\$120	h
Disposal Costs	Silt/Sediment Disposal	\$60	m <sup>3</sup>

Source: Ontario Ministry of the Environment (1991), *Stormwater Quality Best Management Practices*.

As an alternative cost measure, a 2,000 m<sup>3</sup> dry pond is expected to have construction costs of about \$35,000.<sup>5</sup> Annual maintenance can be expected to cost about \$1,500.<sup>6</sup> The capital costs of extended detention ponds are expected to be about 10% more than a simple detention pond.

### **Implementation Issues**

- *Design (Size)* – Detention ponds can be applied in small development sites (less than 5 hectares). They are appropriate for a cluster of houses, and are usually readily incorporated into the design of the overall development.
- *Design (Location)* – Dry ponds can be utilized in low visibility developments, either greenfield or brownfield. These ponds may face public opposition in high-density, high-visibility residential or commercial areas since they can be unattractive when dry.
- *Design (Soil)* – Soils may be permeable since it is not necessary to maintain a permanent pool. The water table should be more than 0.5 metres from the bottom of the pond. Bedrock close to the surface will increase excavation costs.
- *Routine Maintenance* – Maintenance is essential to prevent clogging of the inlet/outlet structures, minimize long-term standing water, manage the growth of plants and weeds, and remove accumulated debris. An unsightly pond can have adverse effects on neighbouring property values.

<sup>5</sup> Construction cost (\$C)  $\approx 15.1 \times (\text{Storage Area in Cubic Feet})^{0.69}$  according to Schueler (1987) and transformed to 1999 Canadian dollars.

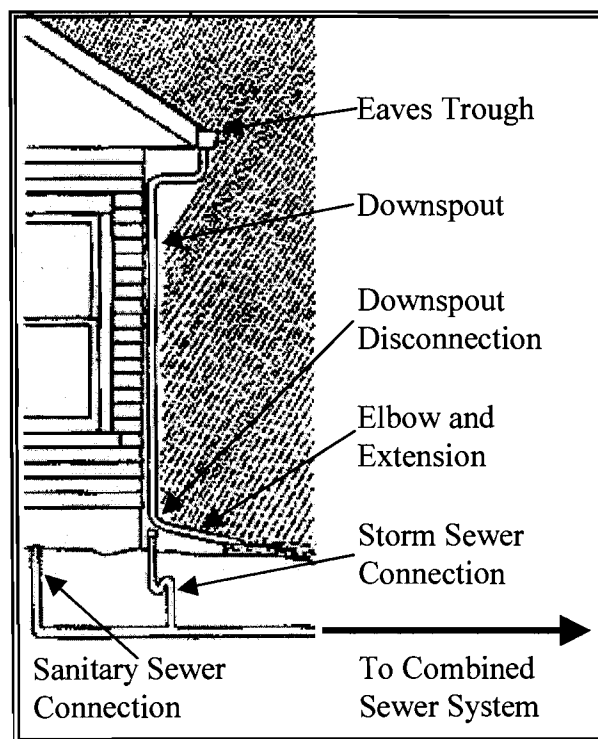
<sup>6</sup> Annual maintenance costs in the range of about 3% to 5% of one-time construction costs are typical, ignoring long term sediment removal.

- *Periodic Maintenance* – Structural repairs and sediment removal will be required, the extent depending on the design and operation of the detention pond. Sediment removal every 5 years is frequently recommended.
- *Safety* – While less dangerous than other storm water quality ponds that are deeper and have permanent pools, detention ponds can pose a safety threat. Restricting access to the ponds and ensuring pond sides are not steeper than 3:1 can minimize safety threats.

## 9 DOWNSPOUT DISCONNECTION

### *Description*

Downspout disconnection (sometimes called roof leader disconnection) represents a cost-effective on-site alternative for reducing the volume and cost of stormwater that requires public management. Runoff from residential rooftops is collected by eaves troughs, which are installed along the edge of the roofline. Water collected in the eaves trough is conveyed to ground level by one or more downspouts. Downspouts may then connect directly into the storm sewer system or in older neighbourhoods into a combined storm and sanitary sewer system.



Disconnecting downspouts brings a number of economic and environmental benefits to the municipality and the homeowner:

- in combined sewer areas, disconnection reduces the amount of combined flow requiring treatment and reduces the threat of CSOs;
- in separated sewer areas, the diverted stormwater reduces volumes of flows conveyed and resulting loads to watercourses;
- downspout disconnection can reduce basement flooding from sanitary sewer backups and leaking downspout connections; and
- environmental benefits can result in terms of cleaner watercourses, groundwater recharge, and availability of “recycled” rainwater.

Source: <http://www.cityfarmer.org/downspout96.html>

Some Canadian municipalities already have voluntary, incentive-driven, or mandatory downspout disconnection programs in place. In these cases, downspouts on existing homes are disconnected from the sewer system, and downspouts on new homes are built without connections to the system.

### *Effectiveness Analysis*

Downspout disconnection is focused on stormwater quantity management. By disconnecting downspouts, less conveyance and treatment infrastructure is needed. In addition, major

environmental benefits emerge as the volume of stormwater direct discharged to watercourses is reduced, and the frequency and severity of combined sewer overflows (CSOs) can be reduced.

Downspout disconnection reduces the amount of stormwater that is either:

- conveyed along a public separated storm sewer system, and ultimately direct discharged to a watercourse; or
- conveyed along a public combined sanitary / storm sewer system, and ultimately treated at a treatment plant.

The amount of stormwater runoff diverted depends on the amount of rainwater intercepted by rooftops (annual rainfall and roof area) as well as the number of downspouts that can be disconnected.

The City of Toronto investigated the effectiveness of a residential rooftop downspout disconnection program. Evidence from a primarily residential area of the City of Toronto suggests that rooftops cover approximately 20% of surface area, indicating the amount of rainwater that could be diverted [J.F. Sabourin and Associates Inc. (1999), Implementation Plan Overview Moore Park / North Rosedale Demonstration Area].

Assuming an annual rainfall of about 700 mm (typical of Toronto, excluding snowfall), disconnection of an average home with a roof area of 140 m<sup>2</sup> would result in diversion of nearly 100,000 litres of stormwater from the sewer system each year. In reality, downspout disconnection usually can be done on about 3/4 of a property's downspouts (without resorting to more complex and costly disconnection schemes) in average density urban areas.

Disconnection is expected to have a small impact on the quality of stormwater runoff conveyed through a combined or separate sewer system. A major quality benefit, however, results to receiving watercourses through avoided CSO incidents. The Toronto study indicates that some parts of the combined sewer system overflowed as many as 15 times per year, resulting in a discharge of stormwater and wastewater to receiving watercourses. It was estimated that disconnecting one quarter of the downspouts in the study area would result in a 50% decrease in the number of CSOs. Disconnecting two thirds of the downspouts would nearly eliminate CSOs. The number of CSOs avoided elsewhere depends on specific features of the sewer system.

### ***Economic Analysis***

The costs of downspout disconnection vary depending on whether a simple or complex disconnection occurs. The costs of a simple disconnection are quite small relative to other lot-level stormwater management alternatives. If a connection already exists, the costs of disconnection have been shown to be as low as:<sup>7</sup>

- labour cost (per house)      \$4.00
- material cost (per house)    \$6.00
- total cost (per house)        \$10.00

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<sup>7</sup> Conservative conversion of data from Kaufman, M., and M. Wurtz (1997), "Hydraulic and Economic Benefits of Downspout Diversion", Journal of the American Water Resources Association, Volume 33, Number 2, April 1997.

At the high-end, some municipal governments have made available a subsidy of about C\$100 to homeowners to disconnect downspouts. This subsidy was estimated to be sufficient to cover the full time and materials costs of a complete disconnection. Materials costs are for downspout extensions, elbows, splash pads, and possibly rain barrels. Note that it may be necessary to deploy rain barrels to manage runoff at some properties, which will cost homeowners about \$100 - \$200 per barrel depending on volume and make.

For some properties, notably those in high density neighbourhoods or with low soil permeability, more complex disconnection techniques may be required, for example using soakaway pits. These alternatives would have additional construction and on-going maintenance costs.

For new home builders, cost savings may actually result from not initially connecting downspouts to the sewer system. Additional savings may be realized because the reduced flows may allow smaller sewers to be built. No estimates of these cost savings are available.

### ***Implementation Issues***

A great deal of experience exists with downspout disconnection programs. However, no firm technical guidelines exist identifying when a disconnection can or cannot be attempted. Rather, a range of property characteristics must be assessed subjectively. The four most important considerations are:

- *Lot Size* – The lot size should be sufficient to provide an area for the diverted runoff to infiltrate. Runoff should not pool significantly, or run across the surface onto a neighbour's property. Pooling and cross-property runoff raise a number of safety and legal issues.
- *Soil Perviousness* – Runoff should be redirected to soft landscaped surfaces such as lawns, gardens, or swales to allow infiltration. If directed to hard landscaped surfaces such as driveways, runoff will flow to the street and sewer system, eliminating potential benefits.
- *Property Grade* – Downspout disconnection works well on properties with small grades. The grades help avoid significant pooling of runoff. Higher grades (for example greater than a few degrees) are too steep to allow infiltration.
- *Proximity to Buildings* – Runoff should not be discharged immediately beside buildings or on a grade which would direct flows to buildings. Runoff reaching a building could cause foundation damage or basement flooding.

As such, a number of safety and legal concerns can arise in consideration of downspout disconnection programs. Safety concerns relate primarily to the threats posed by pooled runoff and ice formation on walkways in the winter months. Legal concerns may arise in respect of either of these, or from foundation damage or basement flooding. Discussions with managers of municipal downspout disconnection programs indicate that these concerns can be mitigated through the use of prudent planning (i.e., ensuring that the disconnection is performed properly, and only disconnecting downspouts where the right lot conditions exist).

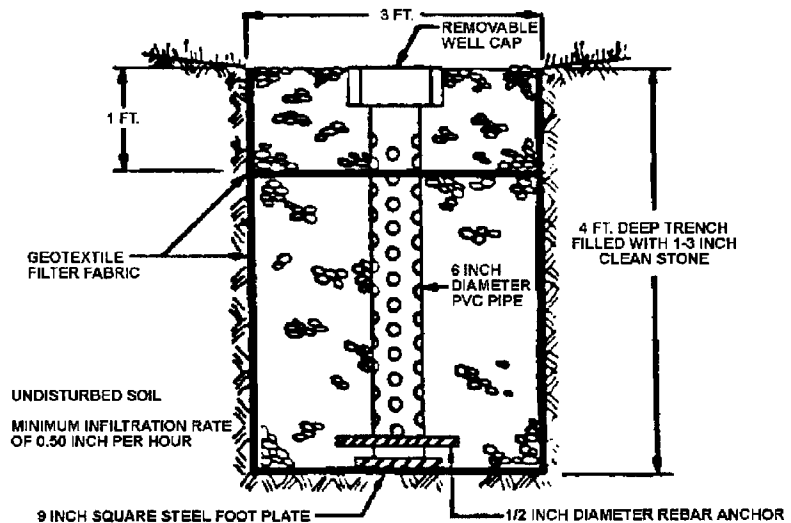


## 10 INFILTRATION TRENCHES

### Description

A conventional infiltration trench is a shallow, excavated trench that has been backfilled with stone to create a narrow underground reservoir. Stormwater runoff diverted into the trench drains from the bottom of the trench into the subsoil and eventually to the water table.

A design variation from the conventional trench includes a dry well to control small volumes of runoff. Enhanced infiltration trenches also include pre-treatment systems to remove additional sediment and oil.



<http://www.epa.gov/owow/wtr1/watershed/Proceed/botts.html>

### Effectiveness Analysis

Infiltration trenches are primarily designed for stormwater quality management, and generally provide little or no stormwater quantity management.

### Stormwater Quality

Infiltration trenches can improve the quality of stormwater runoff. A properly maintained trench can remove both particulate and soluble pollutants. Effective removal of sediment, phosphorus, nitrogen, trace metals, coliforms, and organic matter is accomplished through adsorption by soil particles, and biological and chemical conversion in the soil. Rates of pollutant removal are contingent on the type of soil (sandy soils are less effective at removing nitrates and trace metals than less porous soils). Particulates may also be trapped when an infiltration trench is used as part of a treatment train with other stormwater BMPs (i.e., filter strips, urban forestry, etc.).<sup>8</sup>

Pollutant removal capabilities for infiltration basins that filter the entire amount of captured stormwater follow.

<sup>8</sup> Schueler, T. (1987), *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*.

Pollutant	Removal Efficiency
Plant Nutrients	
Total Phosphorus	High
Total Nitrogen	High
Sediment	
Total Suspended Solids	Very High
Metals	
Trace Metals (Sediment-Bound)	Very High
Organic Matter	
Biochemical and Chemical Oxygen Demand (BOD)	Very High
Oil and Grease	High
Bacteria	Very High

Compiled from Schueler 1987; Schueler, et al. 1992; US EPA 1990; Phillips 1992; Birch, et al. 1992 and others.

### *Stormwater Quantity*

Most infiltration trenches have a minimal impact on stormwater runoff quantity. They can, however, help provide ground water recharge, control peak stormwater flows, and protect against erosion. A significant advantage of infiltration is that in areas with a high percentage of impervious surface, infiltration is one of the few means to provide significant groundwater recharge.

### *Economic Analysis*

Infiltration trenches bring both one-time capital costs and recurring maintenance costs. Costs tend to vary according to the size of the trench, with the following table illustrating construction cost estimates.<sup>9</sup> Following the estimates in the table, an infiltration trench (with a storage volume of 53 m<sup>3</sup>, based on a shallow trench of 0.4 m) would have construction costs of about \$38,200. It is expected that reconstruction would be required after about 15 years. In addition, two types of maintenance costs would be incurred. Sediment/oil removal would cost about \$4,500 per year, and grass cutting would cost about \$150 per year.

Other capital cost estimates was found. Infiltration trenches with a volume of about 30 cubic metres (1 m deep, 1 m wide, and 30 m long) may have capital costs in the range of \$4,000 to \$12,000.<sup>10</sup> Deepening the same trench (for example to 2 m) increases capital costs to \$10,000 to \$30,000. Finally, Schueler provides an alternative formula for estimating capital costs. This formula suggests that an infiltration trench with a storage volume of 53 m<sup>3</sup> would have costs of about \$18,000.<sup>11</sup> Construction costs are relatively variable depending on trench shape and site.

<sup>9</sup> Ontario Ministry of the Environment (1991), *Stormwater Quality Best Management Practices*.

<sup>10</sup> Converted to Canadian dollars from [<http://www.epa.gov/owow/wtr1/watershed/Proceed/botts.html>].

<sup>11</sup> Construction cost (\$C)  $\approx 1,466 \times (\text{Storage Volume in Cubic Metres})^{0.63}$  according to Schueler (1987) and transformed to 1999 Canadian dollars.

Capital Costs	Amount	Unit Cost	Cost
Filter Cloth	400 m <sup>2</sup>	\$12 / m <sup>2</sup>	\$4,800
Pervious Pipes	16 (20m) pipes	\$20 / m	\$6,400
Sand Filter	80 m <sup>2</sup>	\$50 / m <sup>2</sup>	\$4,000
Gravel Storage	160 m <sup>3</sup>	\$50 / m <sup>3</sup>	\$8,000
Excavation	720 m <sup>3</sup>	\$12 / m <sup>3</sup>	\$8,640
Overflow Pipe	20 m	\$240 / m	\$4,800
Seed and Topsoil	400 m <sup>2</sup>	\$3 / m <sup>2</sup>	\$1,200
Observation Wells	2 m	\$180 / m	\$360
<b>Total</b>	--	--	<b>\$38,200</b>

Note: The pervious pipes are to help increase infiltration by spreading runoff through the trench, and are not shown in the earlier diagram.

### ***Implementation Issues***

Although infiltration is a simple concept, infiltration devices must be carefully designed and maintained if they are to work properly. Poorly installed or improperly located devices fail easily, and do not achieve the stormwater quality efficiencies noted above.

- *Applications* – Infiltration trenches take up little land and can be located on or close to residential sites or clusters of sites. Smaller infiltration devices such as infiltration basins and dry wells are aptly suited to manage stormwater quantity from roofs or other surfaces.
- *Sites* – Siting considerations are extremely important in the construction of an infiltration trench. The user of trenches is restricted by soil type, depth of water table, slope, and contributing area conditions, and requires professional assessment.
- *Soils* – It is critical that infiltration devices only be used where the soil is porous to provide stormwater quality benefits. In areas where runoff is polluted, about 1 metre of clearance above the water table is recommended to help prevent groundwater pollution.
- *Drainage* – Infiltration basins should drain within 72 hours to maintain aerobic conditions (which favour bacteria that aid in pollutant removal) and to ensure that the basin is ready to receive the next storm.
- *Climate* – Trenches may not perform well in regions with long, cold winters and deep freeze-thaw levels. Likewise, trenches may not be appropriate in areas with sparse vegetative cover that would have significant sediment levels in runoff.
- *Maintenance* - Maintenance requirements include regular inspections, cleaning of inlets to prevent clogging, mowing and inspection of observation wells to maintain proper operation.<sup>12</sup> Insect, odours, and soggy ground can arise as nuisances.

<sup>12</sup> See <http://h2osparc.wq.ncsu.edu/river/industrial/industri.html>.

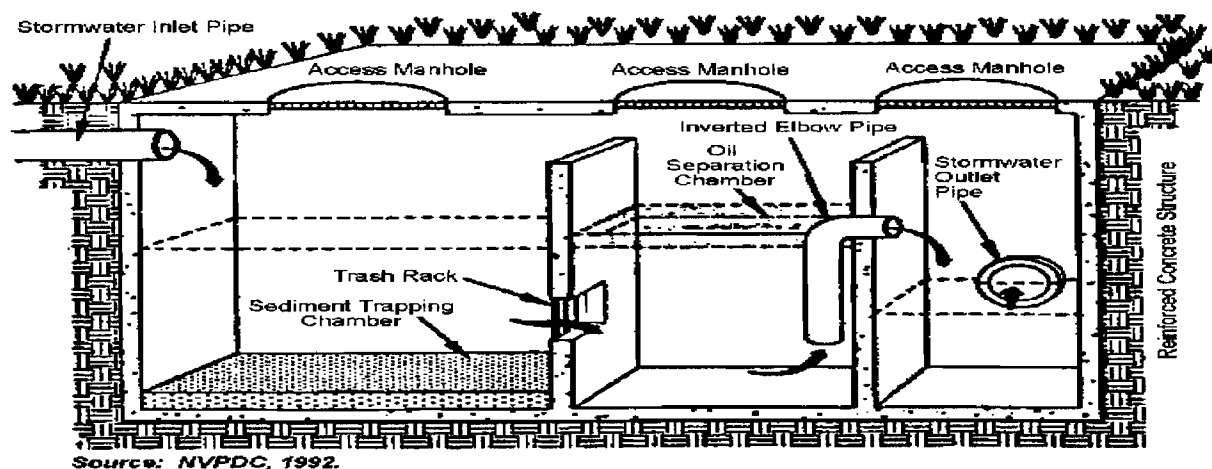
## 11 OIL AND GRIT SEPARATORS

### *Description*

Oil and grit separators (OGS) are structures consisting of one or more chambers that remove sediment, screen debris, and separate oil from stormwater. These structures are also known as oil and water separators or water quality inlets. Their major environmental benefit comes in the form of improved downstream water quality as part of a treatment train. Runoff quantity management is not directly afforded.

Oil and grit separators are particularly well suited to capture particulates and hydrocarbons from small, highly impervious areas such as residential townhouse/apartment parking lots, loading/parking areas at commercial facilities, and gas stations. Two basic types of oil and grit separators are available: the three chamber OGS; and the manhole OGS. A typical model is shown below.

Typical OGS Profile



Source: U.S. Environmental Protection Agency (1996), *Structural Best Management Practices for Storm Water Pollution Control at Industrial Facilities*, at <http://www.epa.gov/owowwtr1/watershed/Proceed/botts.html>.

### *Effectiveness Analysis*

Both the three chamber OGS and the manhole OGS operate under the same general principles. Particulate matter and oil are washed from the ground surface by stormwater runoff and transported to an oil and grit separator. The sediment and oil laden stormwater runoff enters the oil and grit separator and flows into a water-filled chamber. The water-filled chamber has the effect of slowing the velocity of stormwater runoff, allowing some of the particulate matter to settle and allowing suspended oil to rise.

Oil and grit separators are installed underground and are integrated into the storm sewer system. Some OGS have a flow bypass as part of their design. This means that only low flows enter the OGS, and more significant flows from infrequent rainfall events bypass the facility. This bypass reduces the potential for contaminants to be re-suspended and to re-enter the storm sewer system. Alternatively the OGS may be constructed off-line from the main storm sewer system with a pipe from the main storm sewer line to divert only low flows to the OGS.

In many circumstances, stormwater quantity controls are used in conjunction with oil and grit separators. In such cases peak inflows may be reduced so that bypass is not necessary. Designers, however, must recognize the link between the OGS design runoff volume and the volume of storage provided in the OGS. The effectiveness of the OGS is largely dependent on the relative amount of impervious drainage and the size of the OGS, and whether bypass or flushing occurs during a particular event.

The Ontario Ministry of the Environment carried out a comparison study for two types of oil and grit separators. The sites were located in southern Ontario and were of similar land use and drainage area. The results are shown for an average removal rate during 60 runoff events for the three chamber OGS and 43 runoff events for the manhole OGS. The three chamber OGS is larger in size, however, the unit did not include a bypass for large storm events. The manhole OGS design includes a bypass for larger storm events.

#### Efficiency of Oil and Grit Separators

Type of OGS	Chamber Size	Percent Removal		
		TSS	Heavy Metals	Oil /Grease
Three Chamber OGS	52 m <sup>3</sup>	48%	21-36%	42%
Manhole OGS with Bypass	35 m <sup>3</sup>	61%	42-52%	50%

Source: Henry, D., W. Liang, and S. Ristic (1999), *Comparison of Year-Round Performance for Two Types of Oil and Grit Separators*, Presented at the International Congress on Local Government Engineering and Public Works, Sydney, Australia, August 22 – 26, 1999.

These results should be taken as "ballpark", given that effectiveness varies depending on a number of parameters -- for example site characteristics, the ratio of flow to capacity, flow velocity, the OGS manufacturer, and even frequency of OGS maintenance.

#### Economic Analysis

Four main cost categories are associated with the acquisition and operation of an oil and grit separator: [i] one-time capital costs; [ii] one-time installation costs; [iii] recurring maintenance costs; and [iv] recurring waste disposal costs.

The capital costs depend primarily on the model and size of the OGS purchased. Installation costs vary significantly depending upon whether the OGS is placed in a greenfield or brownfield development. Maintenance costs vary by device, site, and practice, while waste disposal costs are location-specific.

A summary of the annualized costs associated with oil and grit separators is shown below. In general, a typical OGS system can be expected to cost about \$2,000 or more (undiscounted) per year over a 30-year lifetime. Again, these costs are "ballpark", given their variability by site and application. Higher costs would result for large models, for brownfield retrofits, and in areas with more frequent maintenance requirements.

#### Life Cycle Costs of Oil and Grit Separators (1999 \$C)

Cost Category	A	B	C	D
Annualized Purchase Cost	\$1,880	\$480	\$1,260	\$560
Annualized Installation Cost		\$120	\$320	unknown
Annual Maintenance Cost	\$620	\$1,400	\$600	\$6,640
Annual Disposal Cost				unknown
Total Annual Cost	\$2,500	\$2,000	\$2,180	\$7,200

A: Case study of a OGS purchase and operation from Edmonton, AB.<sup>13</sup>

B: Data provided by an un-named OGS manufacturer, based on a medium-sized system.

C: Data provided by an un-named OGS manufacturer, based on a medium-sized system.

D: Information from an Ontario Ministry of Environment publication.<sup>14</sup>

#### Implementation Issues

- *Applications* – Oil and grit separators can operate as a pre-treatment device in a train of BMPs, or as a stand-alone water quality (not water quantity) BMP in situations where a lower level of protection is needed. They provide relatively efficient removal of debris, sediment, and hydrocarbons, sometimes trap trash, debris, and other floatables, but have minimal effects on nutrients and organic matter.
- *Design Considerations* – Inlets typically serve small, highly impervious areas, typically less than 4,000 square metres (about 1 acre). Because several small catch basins can be distributed over a large drainage area, they may prove advantageous over constructing a single large structure downstream.
- *Land Uses* – OGS systems can be used in urban areas where land use constraints prohibit the use of other BMPs. They can be installed in almost any soil or terrain, which allows their use near or at the impervious surfaces contributing heavily to the stormwater runoff. Since these devices are underground, appearance is not an issue and public safety risks are low.
- *Maintenance* – Oil and grit separators require regular inspection and cleaning to remove sediment, accumulated oils and grease, floatables, and other pollutants (at least twice annually and after major storm events). Some concern exists over the toxicity of trapped residuals, which may require disposal as a hazardous waste. Odours are sometimes a problem.

<sup>13</sup> See Labatiuk, C., V. Nataly, and V. Bhardwaj (1997), *Field Evaluation of a Pollution Abatement Device for Stormwater Quality Improvement*, Presented at the 1997 CSCE Environmental Engineering Conference.

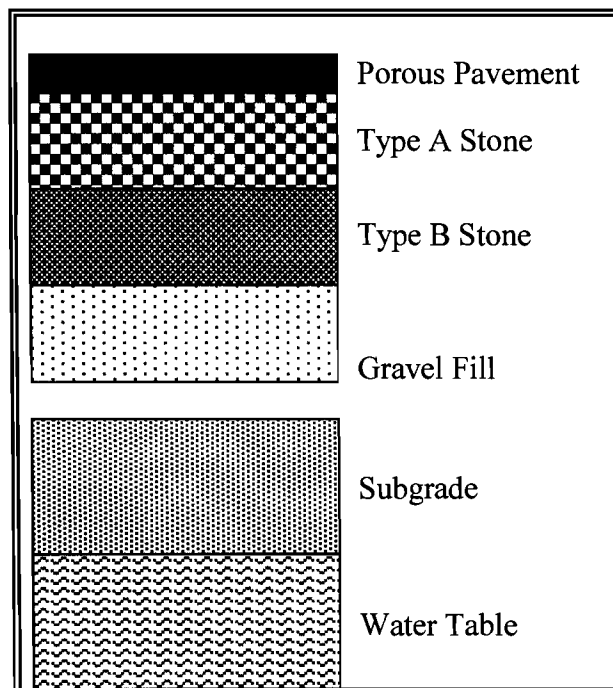
<sup>14</sup> See Ontario Ministry of Environment (1991), *Stormwater Quality Best Management Practices*.

## 12 POROUS PAVEMENT

### *Description*

Porous pavement is an alternative to conventional pavement that is intended to reduce impervious area and subsequently minimize the volume of surface runoff. It can be used for areas that are traditionally covered with an impervious surface such as driveways, sidewalks, and low-traffic roads. While primarily focused on stormwater quantity management, porous pavement can provide important quality benefits as well.

Porous pavement follows one of two basic designs. *First*, it may be comprised of asphalt or concrete that lacks the finer sediment found in conventional cement. *Second*, porous pavement may be formed with modular, interlocking open-cell cement blocks laid over a base of coarse gravel. Both designs typically include layers of coarse aggregate stone beneath the pavement for stormwater storage prior to exfiltration into surrounding soils.



When operating properly, porous pavement can reduce surface runoff and increase groundwater recharge, meaning that:

- new storm sewer systems can be designed for a reduced flow capacity and at lower cost since runoff otherwise conveyed to the storm sewer will be infiltrated into the ground;
- less runoff will enter a combined storm and waste water system, thereby reducing the costs of treating combined storm and waste water mixture at treatment plants; and
- the number and frequency of combined sewer overflows are reduced since the decreased volume of stormwater places less demand on the combined sewer system.

Source: from <http://www.gis.net/~dmiller/porpave.html>

### *Effectiveness Analysis*

Porous pavement operates primarily as a stormwater quantity management tool, but also provides quality management that can be significant.

### *Stormwater Quantity Management*

At least one study in Ontario investigated the infiltration capacity of porous concrete pavement.<sup>15</sup> Infiltration rates were determined for four sites with travelled and untravelled sections, as shown below. For these sites the travelled sections had lower infiltration rates, and infiltration rates also decreased with age. These realities may be attributed to compaction of the sub-base material and surface accumulation. Two of the sites were regenerated through either street sweeping / vacuuming or manual removal of the upper five millimetres of sediment accumulation. In both cases, maintenance led to increases in infiltration rates.

Land Use	Age (Years)	Infiltration Rates (mm/hr)			
		No maintenance		Maintenance	
		Travelled	Untravelled	Travelled	Untravelled
Parking Lot	3	3.5	8.2	5.6	9.9
Parking Lot	1	8.5	21.5	47.1	32.6
Lane	1	-	34.3	-	-
Lane	3	7.9	-	-	-

The study concluded that over time infiltration rates would be reduced due to compaction and accumulation of sediment regardless of the frequency of maintenance. Routine maintenance should be carried out to help remove the accumulation of sediment, particularly in the spring since winter sanding and salting can block the porous areas and prevent infiltration. Other studies show that modular, interlocking, open-cell concrete block type tends to remain effective for considerably longer than asphalt or concrete porous pavement.<sup>16</sup>

### *Stormwater Quality Management*

Operating porous pavement systems have been shown to have high removal rates for sediment, nutrients, organic matter, and trace metals. Two monitoring studies were conducted in the U.S. indicating high long-term removal of sediment (up to 80%), phosphorous (up to 60%), and nitrogen (up to 80%), and high removal rates for metals and organic matter.<sup>17</sup>

The majority of the removal occurs as the result of the exfiltration of runoff into the subsoil, and subsequent adsorption or straining of pollutants within the subsoil. Pollutants are removed through adsorption, straining, and microbial decomposition in the subsoil below the layers of course aggregate, and trapping of particulate matter within the aggregate layer.<sup>18</sup>

<sup>15</sup> Kresin, Christopher, (1996), *Long-term Stormwater Infiltration Through Concrete Pavers*, University of Guelph Thesis.

<sup>16</sup> See the Wyoming Department of Environmental Quality (1999), *Urban Best Management Practices for Nonpoint Source Pollution*.

<sup>17</sup> Wyoming Department of Environmental Quality (1999), *Urban Best Management Practices for Nonpoint Source Pollution*.

<sup>18</sup> Schueler, T.R. (1987), *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*.



### *Economic Analysis*

The economic costs of porous pavement relate to:

- *first*, one-time construction costs; and
- *second*, on-going maintenance costs.

Porous pavement is expected to cost at least as much as traditional pavement, though different experiences exist. Some sources identify that “porous pavement is expected to cost no more than conventional pavement on low-traffic applications such as parking lots.”<sup>19</sup> Other sources indicate that porous pavement can cost “up to 50% more” than traditional pavement applications.<sup>20,21</sup> One somewhat dated source estimates that the construction costs of a porous pavement parking lot is about \$50/m<sup>2</sup>, or about 10% more than conventional paved lot with stormwater inlets and subsurface piping.<sup>22</sup>

On-going maintenance costs are dependent on the type and frequency of maintenance. For example, maintenance of porous pavement could consist of quarterly vacuum sweeping. Such a practice has been estimated to be about 1%- 2% of the original construction costs.<sup>23</sup> Other more substantive costs may be required if maintenance is insufficient or infrequent, for example through the wholesale regeneration of a clogged system. No cost estimates for such major maintenance were found.

### *Implementation Issues*

Porous pavement is not suitable for all applications that conventional pavement is, and requires careful consideration. In particular, porous pavement is more fragile than conventional surfaces, is appropriate for low-volume, light-weight traffic, and tends to require significant attention to maintenance. Furthermore, U.S. experience shows that a large percentage of applications of porous pavement have failed due to clogging.

- *Site* – Most porous pavement sites are relatively small in size, usually less than four hectares. This primarily reflects the perceived economic (traffic types) and liability (groundwater quality) problems potentially associated with larger applications.
- *Maintenance* – The major disadvantage of porous pavement is that sites tend to have high failure rates due to clogging either from improper construction, accumulated sediment and oil, winter maintenance activities (salting/sanding/ploughing), or resurfacing. Quarterly vacuum sweeping or other maintenance is needed to help maintain porosity.

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<sup>19</sup> See <http://www.gis.net/~dmiller/porpave.html>

<sup>20</sup> Cahill Associates (1991), *Limiting NPS Pollution from New Development in the New Jersey Coastal Zone*, New Jersey Department of Environmental Protection.

<sup>21</sup> Silverman, G.S., and M.K. Stenstrom (1989), “Source Control of Oil and Grease in an Urban Area”, in *Design of Urban Runoff Quality Controls*, ed. L.A. Roesner, B. Urbonas, and M.B. Sonnen.

<sup>22</sup> From James, W. and R. Shahin (1997), *A Laboratory Examination of Pollutants Leached from Four Different Pavements by Acid Rain*.

<sup>23</sup> <http://www.epa.gov/owow/nps/MMGI/Chapter5/ch5-2e.html>

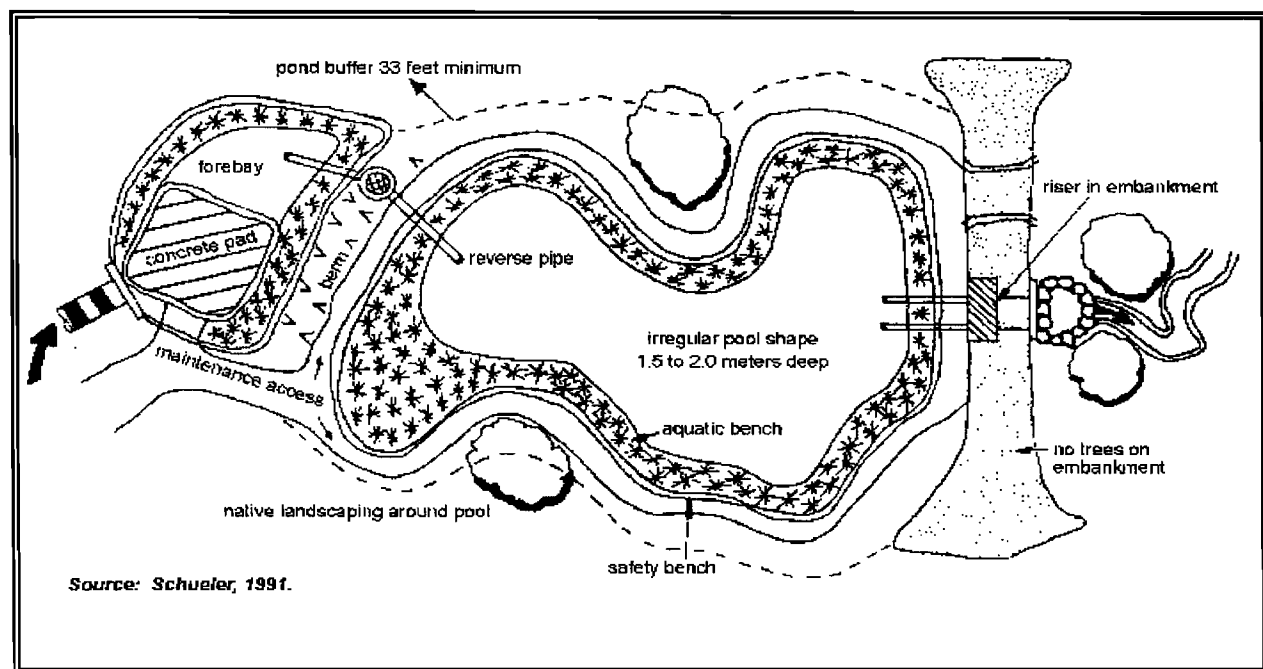
- *Climate* – Porous concrete should not be used in areas where freezing conditions will occur, since water that enters the voids in the concrete will expand during freezing and create cracks in the material. Porous pavements need to provide the required strength to withstand the freeze and thaw cycle in Canada, likely increasing costs.
- *Traffic* – Porous paving is limited to low traffic volume driveways and parking lots since it is subject to rutting, potholes and cracking from high traffic loads. Its use is sometimes recommended for lightly trafficked satellite parking areas.
- *Grade* – In general, porous paving materials should be installed at a fairly flat grade (<2.5%). Where possible, ponding areas in untravelled or little travelled areas should be provided to increase infiltration of stormwater.
- *Soil* – Porous paving materials rely on the ability to infiltrate stormwater to the native soil in a relatively short period of time, and should only be implemented where the native soils have a low clay content (less than 30%). Soils classified as a loam, sandy loam, loamy sand, or sand are appropriate for systems that rely on infiltration.
- *Water Table* – The groundwater table should be located more than one metre below the bottom of the coarse aggregate. This will ensure that water will infiltrate to the native soils and migrate downwards to the groundwater table. If the groundwater table intercepts the aggregate, infiltration will not occur, storage capacity will be reduced, and rutting may occur.
- *Environment* – Porous paving materials should not be used in highly polluted areas (such as industrialized sites or high traffic roads) and areas where contamination of the native soils exists. In these situations infiltration of stormwater may adversely impact the quality of groundwater.

## 13 RETENTION PONDS

### *Description*

Retention ponds, also called wet ponds, maintain a permanent pool of water in addition to temporarily detaining stormwater. This permanent pool of water is the principal distinguishing feature between retention ponds and detention ponds.

One example of a wet pond, known as an enhanced wet pond, is illustrated below. An enhanced wet pond is distinguished from a simple wet pond by the existence of a forebay designed as an additional trap to incoming sediment.



Source: Drawn from [<http://www.epa.gov/owowwtr1/watershed/Proceed/botts.html>].

### *Effectiveness Analysis*

Retention ponds bring both stormwater quantity and quality benefits. These ponds fill with stormwater and release most of it over a period of a few days, slowly returning to its normal depth of water. Some stormwater infiltrates underlying soils, and some is evaporated. This process marks a small reduction in stormwater quantity.

Wet ponds help reduce frequent peak stormwater discharges which, in turn, controls downstream flooding and reduces scouring and erosion of streambanks. Because these ponds tend to have a large amount of storage, peak flows are delayed. The extent of these stormwater quantity benefits depends on the size of the pond, volume of inflow, and rate of release, among other factors. These peak flow benefits require detailed stormwater management models to estimate.

Retention ponds provide stormwater quality benefits through several mechanisms, including:

- gravitational settling of suspended particulates;
- biological uptake of pollutants by plants, algae, and bacteria; and
- decomposition of some pollutants.

The exhibit below describes pollutant removal levels for nutrients, sediment, metals, organic matter, oil and grease, and bacteria. In general, retention ponds provide more effective pollutant removal than other stormwater management devices. Negligible removal of soluble pollutants (such as salt) is provided.

Pollutant	Removal Efficiency
Plant Nutrients Total Phosphorus Total Nitrogen	Moderate to High Moderate
Sediment Total Suspended Solids	High
Metals Lead Zinc	High Moderate
Organic Matter Biochemical and Chemical Oxygen Demand	Moderate
Oil and Grease	High
Bacteria	High

Source: Compiled from Schueler 1987; Schueler, et al. 1992; US EPA 1990; Phillips 1992; Birch, et al. 1992 and others.

The following exhibit is a tabulation of percent removal in two retention ponds that were monitored in Southern Ontario. It is important to note that these removal efficiencies will be slightly lower during the winter/spring season since the permanent pool will be completely or partly frozen.

Pollutant	Percent Removal (Summer/Fall Season)	
	Wetland (Retrofit) <sup>1</sup>	Wet Pond <sup>2</sup>
Total Suspended Solids	80%	87%
Total Phosphorus	41%	79%
Oil and Grease	--	79%
E-coli	53%	--
Metals (non-soluble form)	48-83%	60-80%

Source 1: SWAMP (1998), *Performance Assessment of a Retrofit Stormwater Quality Detention Pond, Harding Park, Richmond Hill.*

Source 2: SWAMP (1998), *Performance Assessment of a Highway Stormwater Quality Retention Pond, Rouge River, Toronto.*

Design flaws and/or poor maintenance can upset the efficacy of retention ponds. Design flaws primarily relate to flows “short-circuiting” the facility, and poor maintenance practices relate to infrequent or lack of maintenance. Both reduce the stormwater quality benefits. More is said of these and other implementation issues below.

### *Economic Analysis*

Retention ponds are among the more expensive stormwater best management practices. Installing and operating a retention pond involves four main cost categories:

- one-time capital costs;
- one-time installation costs;
- recurring maintenance costs; and
- recurring waste disposal costs.

All four categories vary according to the size of the retention pond, though these BMPs are among the most expensive cluster-level stormwater management devices. In areas where land is expensive and space is at a premium, retention ponds may not be appropriate.

The following table illustrates the costs associated with retention ponds.

Cost Category	Type of Cost	Price	Unit
Capital Costs	Rip Rap (Inlet / Spill)	\$12	m <sup>2</sup>
	Riser	\$1,800-\$7,200	n/a
	Outlet Pipe (Concrete, 450mm)	\$250	m
Installation Costs	Excavation	\$12	m <sup>3</sup>
	Earthworks	\$4	m <sup>3</sup>
	Vegetation (Aquatic and Terrestrial)	\$1	m <sup>2</sup>
Maintenance Costs	Landscaping	\$2	m <sup>2</sup>
	Sediment Removal (Every 10 Years)	\$1	m <sup>2</sup>
	Removal Labour	\$120	h
Disposal Costs	Sediment Disposal	\$60	m <sup>3</sup>

Source: Ontario Ministry of the Environment (1991), *Stormwater Quality Best Management Practices*.

As an alternative cost measure, a 2,000 m<sup>3</sup> wet pond is expected to have construction costs of about \$50,000.<sup>24</sup> Annual maintenance of the pond could be expected to be about \$2,000.<sup>25</sup>

<sup>24</sup> Construction cost (\$C)  $\approx 10.2 \times (\text{Storage Area in Cubic Feet})^{0.75}$  according to Schueler (1987) and transformed to 1999 Canadian dollars.

<sup>25</sup> Annual maintenance costs in the range of about 3% to 5% of one-time construction costs are typical, ignoring long-term sediment removal.

### ***Implementation Issues***

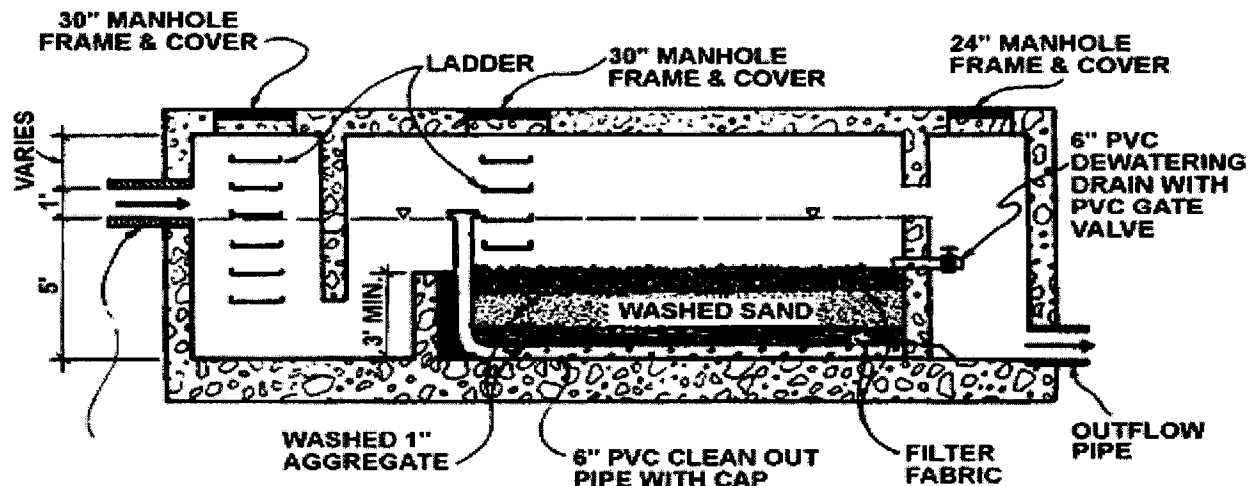
- *Design (Shape)* – Improper design shape can result in “short-circuiting” and a reduction in pollutant removal efficiency. To maximize pollutant removal benefits, a long distance between inlet and outlet is needed (a 3:1 or greater ratio of length to width is appropriate). Where the pond shape is not ideal this can be achieved by a system of low berms that force stormwater to travel longer distances to the outlet.
- *Design (Size and Depth)* – A traditional wet pond requires a minimum area of 2,500 m<sup>2</sup> and is about 1-2 metres deep. Wet ponds are not well suited to very small developments because of their size, but are appropriate for a cluster of houses. The development site should be a minimum of five hectares in area in order to sustain the permanent pool in the retention pond. In a retention pond the design volume and depth of the permanent pool is critical for the efficient removal of pollutants.
- *Design (Soil)* – Where soils are permeable it may not be possible to maintain a permanent pool. In areas with permeable soils, a pond liner is recommended. The liner can be a layer of impermeable clay soil or a synthetic (plastic) liner. Alternatively it may be possible to compact underlying soils.
- *Design (Slopes)* – The side slopes of a retention pond should be no steeper than 3:1 to avoid excessive erosion, and not flatter than 20:1 to provide a permanent pool of sufficient volume and depth that is capable of efficient pollutant removal.
- *Design (Area)* – A buffer strip, about 10 metres wide, should surround a retention pond. The buffer strip should be planted with a mix of low maintenance vegetation, and should be tolerant to changes in the depth of water in the pond.
- *Design (Site)* – Because many people find retention ponds to be aesthetically pleasing, they can be sited in both low and high visibility areas. The pool of water can enhance property values as well as the aesthetic and recreational value of the area.
- *Routine Maintenance* – Retention ponds require regular inspection, landscaping (mowing), and cleaning of inlets and outlets. Care must be taken to control nuisance insects (especially mosquitoes), weeds, algae, and odours.
- *Periodic Maintenance* – Structural repairs and sediment removal will be required, the extent depending on the design and operation of the retention pond. Sediment removal every 10 years is frequently recommended, sometimes with costs reaching \$100,000.
- *Safety* – The pond is a potential hazard for nearby residents due to the presence of standing water. The inclusion of a shallow safety bench around the permanent pool of the pond may reduce the hazards. Additionally, growth of dense vegetation will limit immediate access to residents.

## 14 SAND FILTERS

### *Description*

Sand filters are a stormwater management device used to treat stormwater runoff from residential and commercial buildings, parking lots, and roads. Sand filters generally function only as a storm water quality BMP and do not provide significant quantity reductions.

As the name implies, sand filters work by filtering stormwater through beds of sand and other filtering materials. Sand filters may range from being small or large, and can be relatively complex as the example below illustrates.



Source: <http://www.epa.gov/owow/wtr1/watershed/Proceed/botts.html>

In a sand filter such as the above, stormwater is collected in a ponding area and is allowed to filter through a layer of aggregate and a filter cloth to remove sediment. The water then filters through a sand layer that is at least 0.5 m deep. As stormwater filters through these layers, pollutants such as heavy metals, sediment, E. coli, and phosphorus are removed. The runoff is then collected in underground pipes and conveyed.

### *Effectiveness Analysis*

The Regional Municipality of Ottawa-Carleton constructed a large sand filter to treat approximately 44 ha of contributing area in 1990. The facility was constructed to provide treatment of stormwater to help improve surface waters in the Rideau River during the swimming season. The land uses contributing runoff to the sand filter are mainly commercial and industrial, and significant amounts of additional development are expected to take place in the future.

The sand filter facility itself consists of:

- a 0.30 m layer of gravel and stone;
- a 1.55 m layer of sand; and
- a series of gravel-filled trenches.

The layer of gravel and stone is capable of supporting maintenance vehicles. Geotechnical fabric is located between the upper layers and the native soils to prevent migration of soil into the filter material. Perforated pipes in the gravel trenches convey the filtered stormwater to a storm sewer, which ultimately outlets to the Rideau River.

Performance monitoring of the facility has been ongoing since 1992. Monitoring results indicate that the facility has exceeded expectations for the removal of heavy metals, sediment, E. coli bacteria, and phosphorus. Pollutant removal rates have consistently exceeded 95% on a loading basis.<sup>26</sup>

It is important to note that the facility is currently performing at approximately 45% of its maximum capacity since the upstream drainage area is only partially developed. It is expected that pollutant removal rates will change when higher capacities are reached.

At a more general level, pollutant removal for sand filters varies depending on the site, runoff, and climate. Overall removal of sediment and trace metals is better than removal of more soluble pollutants because the filter functions by straining particles out of the stormwater. The following table lists some published removal efficiencies for various pollutants.

Pollutant	Removal Efficiency
Plant Nutrients	
Total Phosphorus	Moderate
Total Nitrogen	Moderate
Sediment	Very High
Trace Metals (Sediment-Bound)	Very High
Organic Matter	
Biochemical Oxygen Demand (BOD)	Moderate
Oil and Grease	High
Bacteria	Moderate

Source: Compiled from Schueler 1987; Schueler, et al. 1992; US EPA 1990; Phillips 1992; Birch, et al. 1992 and others.

<sup>26</sup> Lynch, D., R.G. Rooke, C. Melanson, S. Short, M. Trudeau (1998), *Stormwater Infiltration That Works*, Regional Municipality of Ottawa-Carleton.



### ***Economic Analysis***

Construction and maintenance costs of sand filters vary according to the type of sand filter (i.e., design complexity), size of the filter, whether the filter is above or below ground, and the quantity and quality of stormwater treated. This variability is reflected in the relative unavailability and range of existing cost assessments.

Several estimates were found of the costs per unit of stormwater treated by sand filters. One cost estimate suggests that the total cost of the installation of such a system in Canada may be in the range of \$5,000 to \$10,000.<sup>27</sup> An alternative estimate from the U.S. Environmental Protection Agency suggests construction costs of about \$70 - \$555 per cubic metre of runoff treated. Annual maintenance costs of about five percent of the initial construction costs are predicted.<sup>28</sup>

One drawback that has limited the widespread use of sand filters is that they often require a relatively large area. For example, in the U.S., by-laws governing buried sand filters require one square foot of sand filter for every 1 or 2 gallons of wastewater. This means that a homeowner would have to set aside up to 200 square feet (~20 square metres) for such a filter at a cost of roughly \$4,000.<sup>29</sup>

### ***Implementation Issues***

- *Site Considerations* – Sand filters are readily adapted to fit space and runoff volume needs. They are particularly appropriate for townhouses or clustered housing, and in ultra-urban areas where space limitations may prohibit the use of other stormwater management methods.<sup>30</sup>
- *Aesthetic Considerations* – Larger above ground sand filter designs without grass covers may not be attractive in residential areas, and may have undesirable odours. Creative landscaping with hedges and other natural barriers can improve the appearance of an above ground sand filter. Restricting activities or access to the portion of a property occupied by a sand filter may be objectionable to a home owner.
- *Climate Considerations* – The effectiveness of both above and below ground sand filters will be diminished during winter months when inflow and outflow pipes may freeze. With the spring thaw, the filter will return to its normal functioning.
- *Maintenance* – Sand filters have long lifetimes and consistent pollutant removal when properly and frequently maintained. Normal maintenance includes raking the sand surface and disposing of accumulated litter. The upper few inches of dirty sand must be removed and replaced with clean sand when the filter clogs.

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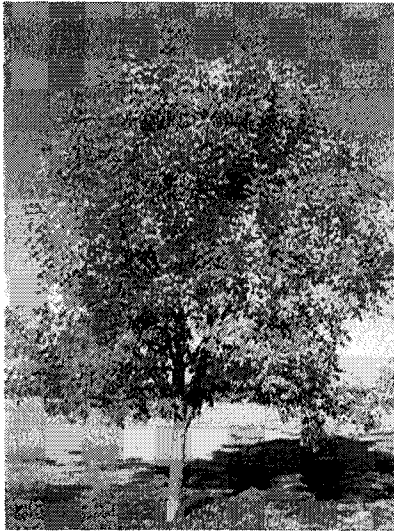
<sup>27</sup> Drawn from <http://www.dal.ca/~cwrs/altern/intfilt.htm>.

<sup>28</sup> From Tull (1990) and Schueler et al (1992) [<http://www.epa.gov/owowwtr1/NPS/MMGI/Chapter5/ch5/2e.html>].

<sup>29</sup> Drawn from [<http://twri.tamu.edu/twripubs/Insights/v2n3/article-5.html>].

<sup>30</sup> See US Environmental Protection Agency (1994), *Developments in Sand Filter Technology to Improve Runoff Quality* [<http://www.epa.gov/owowwtr1/NPS/wpt/wpt02/wpt02fa2.html>].

## 15 URBAN FORESTRY



### *Description*

Urban forestry refers to post-development planting or pre-development preservation of trees, shrubs and other ground covers in an urban context. This lot-level BMP is a functional and attractive supplement to residential lawns and has positive implications for property values particularly once trees and shrubs mature.

Studies have been conducted that look at the impact of natural forests on hydrology. These studies demonstrate that urban forests can:

- help reduce the quantity of stormwater flows; and
- help improve the quality of stormwater runoff.

In addition, urban forests convey a number of environmental benefits through air pollutant uptake and greenhouse gas reduction functions.

### *Effectiveness Analysis*

#### *Stormwater Quantity*

Studies show that urban forests help detain stormwater runoff and reduce stormwater quantity. Some rainfall that is intercepted by tree leaves or needles evaporates or evapotranspires. Rainfall that passes through the canopy may fall on soil that is more pervious than it otherwise would be because of the influence of tree roots on soil. The actual runoff quantity benefits are dependent on the species, canopy density, level of maintenance, and time of year.

One Canadian study measured the amount of rain intercepted, retained in the mulch layer, and running off or infiltrated based on a 25 mm rainfall. At a minimum, the results show that a considerable portion, about 25%, is intercepted.

Species	Interception (mm)	Water Retained in Mulch Layer (mm)	Runoff / Infiltration to Soil (mm)
White Spruce	5	7	13
Red Pine	8	8	9
Balsam Fir	8	10	7
Sugar Maple	5	6	14
Aspen	4	19	2

Source: Mahendrappa, M.K. (1982), *Effects of Forest Cover Type and Organic Horizons on Potential Water Yield*.

A second study of interest was completed in Toronto that illustrates the effects of urban forests at a higher level.<sup>31</sup> The study considered the potential effects of increasing the percentage of tree cover in five defined residential blocks. Their analysis, based on a review of other studies, was that the interception capability of trees is about 2 mm, or about 40% of an average rainfall event. The study also shows that increasing the amount of tree cover will reduce the amount of stormwater runoff. For an increase in tree cover from about 25% to 50%, the results indicated that the average potential reduction in annual runoff ranged from about 10%-20%.

### *Stormwater Quality*

Urban forestry can provide limited improvements to runoff quality. Pollutants are removed by plant uptake and storage, preventing soil erosion, and by reducing the overall quantity of stormwater (thereby reducing associated pollutants).<sup>32</sup> Reliable estimates of the stormwater quality benefits of urban forests were not found.

### *Economic Analysis*

Costs of urban forestry depend on whether activity is pre- or post- development. Pre-development urban forestry is quite inexpensive, as existing trees are preserved. Some costs may be associated with using special heavy machinery to keep from damaging the trunks and roots of the selected trees. Costs of post-development urban forestry involve purchasing seedlings and manual planting labour (based on a rough transferal of U.S. experience):

- seedlings cost about \$50 - \$500 per thousand; and
- manual planting labour may cost about \$400 - \$800 per hectare.

Purchasing and planting of mature trees from a nursery is a more expensive alternative. Full costs in the range of \$3,000 - \$15,000 might be incurred.<sup>33</sup>

Canada's Urban Forests Centre surveyed 600 municipalities across the country to gather information on urban forestry activities.<sup>34</sup> The survey uncovered average costs for establishing trees of between \$20 and \$150 per tree. The average annual maintenance costs ranged between about \$3 and \$12 per tree. Costs to developers may be considerably less, since development activities may provide a cost-effective avenue for tree planting activities.

At the highest level, benefit-cost studies have shown a high return to urban forests. For example, one study in California describes the benefits of municipally owned and managed forests as being at least twice as much as the costs.<sup>35</sup> Benefits included air pollutant uptake, aesthetics, temperature moderation, reductions in atmospheric carbon dioxide, and reductions in stormwater runoff.

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<sup>31</sup> John van Nostrand Associates (1999), *Demonstration of Non-Structural Storm Water Management Practice: Garrison Creek*.

<sup>32</sup> Schueler, T. (1987), *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*.

<sup>33</sup> Schueler, T. (1987), *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*.

<sup>34</sup> Urban Forests Centre (1996), *The State of Canada's Municipal Forests*.

<sup>35</sup> McPherson, E. et al (1999), *Benefit-Cost Analysis of Modesto's Municipal Urban Forest*.

### ***Implementation Issues***

Urban forestry is a stormwater BMP with virtually limitless applications that can be scaled to suit any size requirements. Trees make an attractive addition to residential landscaping, and produce between 30% - 50% less runoff than lawns,<sup>36</sup> and provide food, cover, and nesting sites for wildlife. Some of the related benefits of urban forests include noise absorption, shade, privacy screening, moderation of local temperatures, and provision of a wind barrier.<sup>37</sup> These all serve to increase property values.

A number of implementation issues are important.

- *Site Considerations* – Areas expected to have significant foot traffic are not suitable for urban forestry, as natural ground covers will compact and eventually erode. Urban forests have the greatest quantity impacts where they are planted in a continuous dense stand that is allowed to naturalize. Trees should not be planted where branches will encroach upon overhead wires or roots will damage building foundations (or driveways and sidewalks).
- *Species* – Consideration should be given to the types of species that best flourish in a particular region. In addition, care should be taken in selecting a species appropriate to the individual site (ex., moisture, winds, and soil pH and fertility).
- *Planting the Tree* – The ideal time to plant trees and shrubs is during the fall after leafdrop or early spring before budbreak. This period of cool weather allows plants to establish roots in their new location before spring rains and summer heat stimulate new growth.
- *Maintenance* – Some maintenance is required for urban forestry. In the first few years after planting, seedlings require watering, weed and rodent control, and staking. Furthermore, if mulch is allowed to develop under the tree canopy, more rainfall will be detained since the mulch layer tends to have a relatively high water holding capacity.<sup>38</sup>
- *Energy Considerations* – The east, west, and south walls of your house receive the most sun. Deciduous trees around a house will provide shade, reducing cooling bills in summer. Trees can also save energy in winter. A row of evergreen trees on the north side of a house (or the side with prevailing winter winds) will serve as a windbreak and lower heating costs.

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<sup>36</sup> Pitt, D., W. Gould, and L. LaSota (1986), *Landscape Design to Reduce Surface Water Pollution in Residential Areas*.

<sup>37</sup> Schueler, T (1987), *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*.

<sup>38</sup> Mahendrappa, M. (1982), *Effects of Forest Cover Type and Organic Horizons on Potential Water Yield*, Canadian Hydrology Symposium, 1982, Fredericton, New Brunswick.

## 16 VEGETATIVE PRACTICES

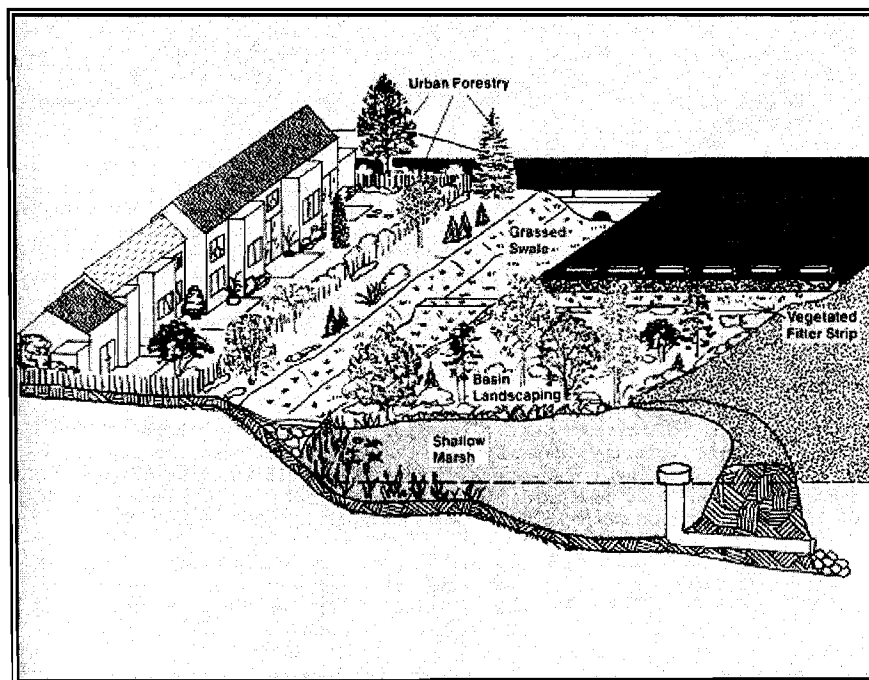
### *Description*

Vegetation is often employed as part of a BMP system to slow runoff and help stormwater infiltrate the soil and settle particulates before entering another treatment device. Two frequently used vegetative measures, filter strips and grassed swales, are described below.

Filter strips provide stormwater quality controls. They are bands of close-growing vegetation, usually grass, planted between a source area and receiving water or channel. Filter strips can include shrubs or woody plants that help stabilize the grass strip. They are often used as pre-treatment devices for other stormwater control practices such as infiltration basins and trenches. Such strips are used primarily in residential areas around streams or ponds, where runoff does not tend to be heavily polluted and an additional level of quality control is desired.

Grassed swales are shallow earthen channels covered with a dense growth of a hardy grass. In a residential setting, swales look like an extension of a front lawn, and can be used as alternatives to curb and gutter stormwater systems. This method is again usually used to provide pre-treatment before runoff is discharged to treatment systems, providing initial water quality improvements. Swales provide some reduction in stormwater pollution by filtering sediment and other matter. They also slow runoff and reduce peak flows.

The following exhibit provides a view of vegetated filter strips and grassed swales.



Source: Schueler, T (1987), *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*.

A grassed swale and perforated storm sewer system is a related stormwater conveyance system that may be used in areas where the streets are constructed without curbs. The system consists of a shallow grassed ditch that is underlain by a gravel trench. A continuous length of perforated pipe is located in the gravel trench. A layer of grass and sod filters the stormwater by removing suspended sediment and trash before it enters the gravel trench. In addition, a layer of synthetic fabric surrounds the gravel trench, providing additional filtration. Once the trench is at capacity, stormwater is conveyed by the perforated sewer system to an outlet such as a traditional closed storm sewer system.

### *Effectiveness Analysis*

Both filter strips and grassed swales serve to reduce the quantity of stormwater runoff by slowing flows and providing an area for increased infiltration. In addition, these vegetative practices provide a means for increased groundwater recharge, an important consideration in urban areas facing groundwater supply concerns. The extent that stormwater quantity benefits are achieved depends primarily on the volume and timing of stormwater, the size of the device, vegetative cover, ground slope, and soil porosity.

Filter strips reduce pollutants such as sediment, organic matter, and trace metals by the filtering action of the vegetation, infiltration of pollutant-carrying water, and sediment deposition. They are less effective at removing soluble pollutants. Although studies indicate highly varied effectiveness, treed filter strips can be more effective than grass strips alone because of the greater uptake and long-term retention of plant nutrients. Properly constructed treed and grassed filter strips can be expected to remove more than 60% of the particulates and perhaps as much as 40% of the plant nutrients in urban runoff.

Grassed swales prevent erosion, filter sediment, and provide some nutrient uptake. Pollutants such as suspended solids and trace metals are removed from surface flow by the filtering action of the grass, sediment deposition, and infiltration into the soil. The efficiency of swales in removing pollutants is moderate to low depending on the quantity of flow, the slope of the swale, the density and height of the grass, and the permeability of the underlying soil. Research on grassed swales has found 30% - 90% reductions in solids and 0% - 40% reductions in total phosphorus loads.

Typical pollutant removal efficiencies for filter strips and grassed swales are shown below.

<b>Pollutant</b>	<b>Removal Efficiency</b>
Plant Nutrients	Low
Sediment	Moderate
Trace Metals	Moderate
Organic Matter	Low
Oil and Grease	Moderate
Bacteria	Low

Source: Compiled from Schueler 1987; Schueler, et al. 1992; US EPA 1990; Phillips 1992; Birch, et al. 1992 and others.

Two monitoring studies for grassed swales and perforated storm sewer systems-- one in Ottawa and one in Toronto -- find that the systems are relatively efficient in managing stormwater quality.<sup>39</sup> Results from these studies are shown below. These pollutant removal efficiencies highlight differences that can be achieved across different sites, land uses, soils, and drainage areas.

Study	Suspended Solids	Heavy Metals	Phosphorus	Nitrogen
Ottawa	90%	75% - 93%	75%	70%
Toronto	75%	25% - 90%	--	--

### *Economic Analysis*

Vegetative BMPs are relatively inexpensive to establish and maintain. Grassed swales are even described as being more economical than curb and gutter drainage systems from a capital and operations cost perspective.<sup>40</sup>

A description of costs of vegetative BMPs is provided below. These costs include any necessary earth moving and shaping. Costs of vegetative practices excluding earth moving and shaping are much smaller.

Device	Type	Cost	Unit
<b><i>Filter Strips</i></b>			
	Topsoil, Grading, Sodding (Turf)	\$6	m <sup>2</sup>
	Hydroseeding (Turf), Grading, Mulch	\$3	m <sup>2</sup>
	Tree and Shrub Planting, Grading	\$18	m <sup>2</sup>
<b><i>Grassed Swales</i></b>			
	Sodded Swale	\$36	m

Source: Ontario Ministry of the Environment (1991), *Stormwater Quality Best Management Practices*.

### *Implementation Issues*

Grassed swales should be constructed in consideration of the following realities.

- *Applications* – Swales can provide runoff control for single-family residential lots. They are inappropriate for controlling runoff from larger facilities, and are usually insufficient to manage runoff from substantial rainfall events.
- *Design (Soils)* – Swales are less effective in regions with sandy soils, as sandy soils contribute to collapse of swale walls. Furthermore, sandy soil conditions influence the extent that alternative species of vegetation can grasp hold and flourish.

<sup>39</sup> J.F. Sabourin and Associates Inc. (1999), *Performance Review of Grass Swale - Perforated Storm Sewer Systems*.

<sup>40</sup> US EPA, Office of Water [<http://www.epa.gov/owow/nps/MMGI/Chapter5/ch5-2e.html>].

- *Design (Flows)* – Swales operate efficiently under conditions when maximum flow rates do not exceed 0.5 m/s. Therefore, the suitability of a swale depends on its area, slope, and imperviousness of the contributing watershed.
- *Maintenance* – Swales require maintenance including periodic inspection, mowing at least twice each year, fertilizer application, and repair and reseeding of washed out areas and bare spots. Higher runoff velocities increase the frequency of required maintenance.

Filter strips should be constructed in consideration of the following realities.

- *Applications* – Filter strips can be utilized in urban settings for treating rooftop runoff and runoff from lawns and other pervious areas from small properties. They are not suitable to control runoff from large parking lots or commercial/industrial establishments.
- *Design (Soils)* – The ability of filter strips to remove nutrients from runoff improves where clay soils or organic matter are present. Filter strips work best when established with a minimum width of 15-20 metres, and having a relatively low slope.
- *Design (Flows)* – Filter strips have limited effectiveness when runoff velocities approach 0.75 m/s. Because their ability to effectively filter stormwater is limited, contributing areas should be less than 2 hectares in size.
- *Maintenance* – Filter strips require periodic repair, re-grading, and sediment removal as well as re-seeding and re-planting. Inspections may also show the importance of removing dead vegetation. Inadequate maintenance will cause filter strips to be non-functional.